Where is the love?

Experimental translocation of the threatened striped legless lizard (*Delma impar*) and an investigation of the habitat suitability of the invasive African lovegrass (*Eragrostis curvula*)

by

Benjamin Huttner-Koros

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Candidate's Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author’s knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.

Benjamin Huttner-Koros Date: 26/05/2016

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Abstract

Translocation of individuals to patches of suitable unoccupied habitat may be a useful conservation action for dispersal limited species occurring in isolated populations. Where populations of threatened species are certain to be lost due to habitat destruction, salvage and translocation of individuals to suitable unoccupied habitat may mitigate some of the loss if translocation is thoroughly planned and considers the species biology, habitat requirements and threats affecting it (Germano *et al.*, 2015). The striped legless lizard (*Delma impar*) may benefit in both these cases as it occurs in isolated populations, is a grassland habitat specialist, dispersal limited and suffers from ongoing habitat loss. Where uncertainties occur in regards to the species biology, translocation can be used to experimentally test hypotheses, for example habitat preference.

I investigated the use of translocation as a conservation measure for *D. impar*. The suitability of the translocation release site in grass structure, food availability and thermal conditions was investigated to ascertain if the translocation may be successful in the long term. The translocation was used to experimentally test the suitability of African lovegrass (*Eragrostis curvula*) and kangaroo grass (*Themeda triandra*) as *D. impar* habitat in the context of the widespread establishment of the invasive grass African lovegrass at the release site and in the Southern Tablelands. The effects of grass structure, food availability and thermal conditions on *D. impar* selection of microhabitat were investigated. Lastly, short term persistence of the released individuals was determined as a short term indication of the likelihood of translocation success.

D. impar were translocated into four enclosures containing approximately equal sized areas of African lovegrass and kangaroo grass. Fine scale grass structure (1 m^2 scale), food availability and thermal conditions were measured at the source and release site and in each grass type at the release site. *D. impar* occupancy and persistence were determined by conducting ten surveys of artificial refuges (tile grids) in release enclosures and modelling *D. impar* habitat use with generalised linear models.

The translocation release site (Scottsdale Reserve) broadly matched the population source site in vegetation structure and *D. impar* food availability. Summer thermal conditions were cooler at the release site. There were significant differences in vegetation structure, food availability and thermal conditions between African lovegrass and kangaroo grass. African lovegrass provided an inferior feeding habitat than kangaroo grass but had greater structural complexity than kangaroo grass and ground temperatures rarely exceeded maximum lizard critical body temperature.

D. impar selected complex grass structures in both grass species. As grass complexity increased, *D. impar* occupancy increased more rapidly in kangaroo grass than African lovegrass. *D. impar* appeared to occupy African lovegrass pastures, at least in the short two month time frame of this study concurring with previous research that grass structure not grass species is the most important factor for *D. impar* habitat. A cooler summer thermal environment allowing greater hours of activity time and possibly a reduction in predation risk (not tested in this study) are the most likely explanation for *D. impar*'s habitat selection of high complexity grass. The increased *D. impar* occupancy in African lovegrass and in high complexity grass of both species was not due to higher food availability in either situation. The tall and dense characteristic of African lovegrass and relatively short characteristic of kangaroo grass at Scottsdale Reserve and the effect of grass height on the ground thermal conditions is likely to explain the higher *D. impar* capture rate in African lovegrass compared to kangaroo grass.

At the release site, the ecotone between African lovegrass and kangaroo grass may be the highest quality *D. impar* habitat due to the combination of greater food availability in kangaroo grass but suboptimal (hot) thermal conditions and cool thermal conditions and high grass cover in African lovegrass.

There was strong evidence of short term persistence during the two months after release, possibly indicating at least short term release site habitat suitability. The success of the translocation in the long term will only be known after detailed monitoring in the following years.

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Chapter 1: Introduction

1.1 Context

The striped legless lizard (*Delma impar*) is a cryptic semi fossorial reptile distributed across lowland grasslands in South-Eastern Australia (Coulson, 1990{Robertson, 2010 #79)}. Approximately 0.5% of natural temperate grasslands occurring pre European colonization currently remain in Australia (Kirkpatrick *et al.*, 1995) and 5% remain in the ACT (ACT Government, 2005). *D. impar* is listed as vulnerable under the Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC Act), A.C.T Nature Conservation Act and other threatened species legislation. One criteria for listing as vulnerable under the EPBC Act is a greater than 10% probability of extinction in the next 100 years, thus this species is at risk of extinction if threats to its survival are not reduced.

D. impar is threatened by habitat loss and modification driven by urban expansion and intensive land management including overgrazing, pasture improvement and ploughing. *D. impar* has very limited ability to disperse and extant populations are isolated from each other. Urban development in Canberra and Melbourne on land where *D. impar* occurs results in ‘doomed’ populations. Translocation of such doomed populations may be a conservation strategy for this species.

Translocation is the human mediated movement of living organisms from one area, with release in another (IUCN/SSC, 2013). Translocation of individuals to patches of suitable unoccupied habitat may be a useful conservation action for dispersal limited species occurring in isolated populations. Where populations of threatened species are certain to be lost due to habitat destruction, salvage and translocation of individuals to suitable unoccupied habitat may mitigate some of the loss if translocation is thoroughly planned and considers the species biology, habitat requirements and threats affecting it (Germano *et al.*, 2015). *D. impar* may benefit in both these cases as it occurs in isolated populations, is a grassland habitat specialist, dispersal limited and suffers from ongoing habitat loss. Translocation has been identified as a potential conservation action for *D. impar* since at least 1995 (Coulson, 1995; Dorrough and Ash, 1999; Webster *et al.*, 2003). Researching the feasibility of translocation is one objective in the species National Recovery Plan (Robertson and Smith, 2010). However, only one translocation attempt has been made in Victoria and the long term persistence of *D. impar* was uncertain (Parks Victoria, 2002).

1.2 Scope

The primary aim of this research was to apply principles and guidelines from the reintroduction biology literature (for example Seddon *et al.* (2007); Batson *et al.* (2015)) to the translocation of *D. impar*, a reptile hypothesized to benefit due to its low dispersal ability. The aim was to test the use of translocation as a reptile conservation tool which has only infrequently occurred globally (Seddon *et al.*, 2005; Bajomi *et al.*, 2010). A secondary aim was to use the translocation as an opportunity to study the habitat preference of this species, particularly the value of the introduced grass African lovegrass (*Eragrostic curvula*). The translocation release site has been heavily invaded by African lovegrass. However, mixed African lovegrass and native pastures have recorded a high diversity and abundance of native reptiles, surpassing records of native dominated pastures in many cases (B Howland 2015, pers. Comm.). *D. impar* are known to occur and reproduce in exotic grasses (Robertson and Smith, 2010) but the suitability of African lovegrass as habitat is not known.

The release site for the translocation of *D. impar* was Scottsdale Reserve (Bredbo, NSW), owned and managed by Bush Heritage Australia (a private non-governmental conservation organization). This translocation provided an opportunity to reintroduce *D. impar* to a site where it is likely to have occurred in the past, prior to intensive agricultural land use. The translocation was conducted in an experimental framework in response to lack of knowledge on the value of African lovegrass as *D. impar* habitat. It was hoped the study would provide knowledge on the habitat characteristics required for high quality release sites for future releases of *D. impar* at Scottsdale Reserve and elsewhere in the Southern Tablelands.

The effects of vegetation composition and structure, invertebrate prey abundance and ground thermal conditions on the fine scale habitat occupancy of translocated lizards was investigated. Lizards were released into enclosures with approximately equal sized areas dominated by kangaroo grass (*Themeda triandra*) and African lovegrass (*Eragrostis curvula*) and *D. impar* occupancy was monitored ten times over two months.

I aimed to develop a protocol for translocation to be used for this and similar threatened grassland reptiles. The long term goal of the translocation, for which this Honours project contributes to, is the establishment of a self-sustaining population with reproducing individuals at the release site. This Honours project only looked at habitat use, habitat preference and initial persistence during two months following the translocation.

1.3 Expected value

Lizards could be re-introduced (a type of translocation) to unoccupied patches of suitable habitat within their historic range. *D. impar* is susceptible to disturbance, for example overgrazing, pasture improvement and ploughing, but can recolonise areas if suitable habitat re-occurs (Dorrough and Ash, 1999). However, *D. impar* has a low capacity for dispersal as movement is likely to be limited by bare ground and roads preventing the natural recolonization of many isolated patches of suitable habitat. Translocation could be used to return *D. impar* to areas where the disturbance has been removed and suitable habitat exists (Dorrough and Ash, 1999). Lizards could also be translocated from one population to another to increase the genetic diversity of the recipient population if it is considered at risk of in-breeding.

This study provides short term data (and the project will provide long term data) on the feasibility and success of *D. impar* translocation. This is valuable as state governments may in future require land developers to translocate *D. impar* from urban development sites prior to development and require information on the ability for these mitigation measures to be useful. If the long term goals of this project eventually shows the species can be translocated successfully, state governments may enforce translocation of *D. impar* from urban development sites prior to construction.

I argue that translocation should not be a substitute for in-situ conservation, but could be used in situations where individuals are certain to die due to habitat loss. My research also helps clarify *D. impar* habitat preferences which could be used to choose *D. impar* translocation release sites and improve management of grasslands. But, long term persistence data is essential to provide information on the expected persistence and recapture rate of this type of conservation action.

1.4 Research questions

- Is Scottsdale Reserve a suitable translocation release site based on comparing relevant biophysical factors at the release site to the source site, a high quality site (reference) due to high *D. impar* density?
- Do *D. impar* show microhabitat selection based on vegetation composition and structure, and how do biophysical factors (vegetation structure, prey availability and thermal conditions) drive this habitat choice (or lack of choice)?
- To what degree do translocated *D. impar* persist during two months after translocation and can they easily be recaptured to determine this?

1.5 Hypotheses

These research questions and my literature review have led to the following hypotheses:

- *D. impar* will persist at the release site due to similarity in vegetation structure, food availability and thermal conditions.
- Fine scale *D. impar* occupancy will be driven by grass structural complexity. *D. impar* will be greater in areas with high grass structural complexity (areas with varying vegetation height and density).
- *D. impar* will persist in both kangaroo grass and African lovegrass if the grass structural complexity is high.
- *D. impar* prey abundance will be greater in high structural complexity grass.
- Sites with frequently high ground temperature will have low *D. impar* occupancy and will not provide suitable habitat.

- Suitable micro-habitats must have thermal refugia that remain below 40 °C and such refugia is provided by tall tussock grasses of both kangaroo grass and African lovegrass.

The structure of this thesis follows a common format of Introduction (Chapter 1), Literature Review (Chapter 2), Methods (Chapter 3), Results (Chapter 4), Discussion (Chapter 5) and Conclusion (Chapter 6). The discussion examines new information gained on the habitat preferences of *D. impar* and the translocation of *D. impar*. This final chapter also examines the significance of the results in regard to translocation theory and practice and management of grassland reserves. It concludes with recommendations for future translocations and research.

Chapter 2: Literature Review

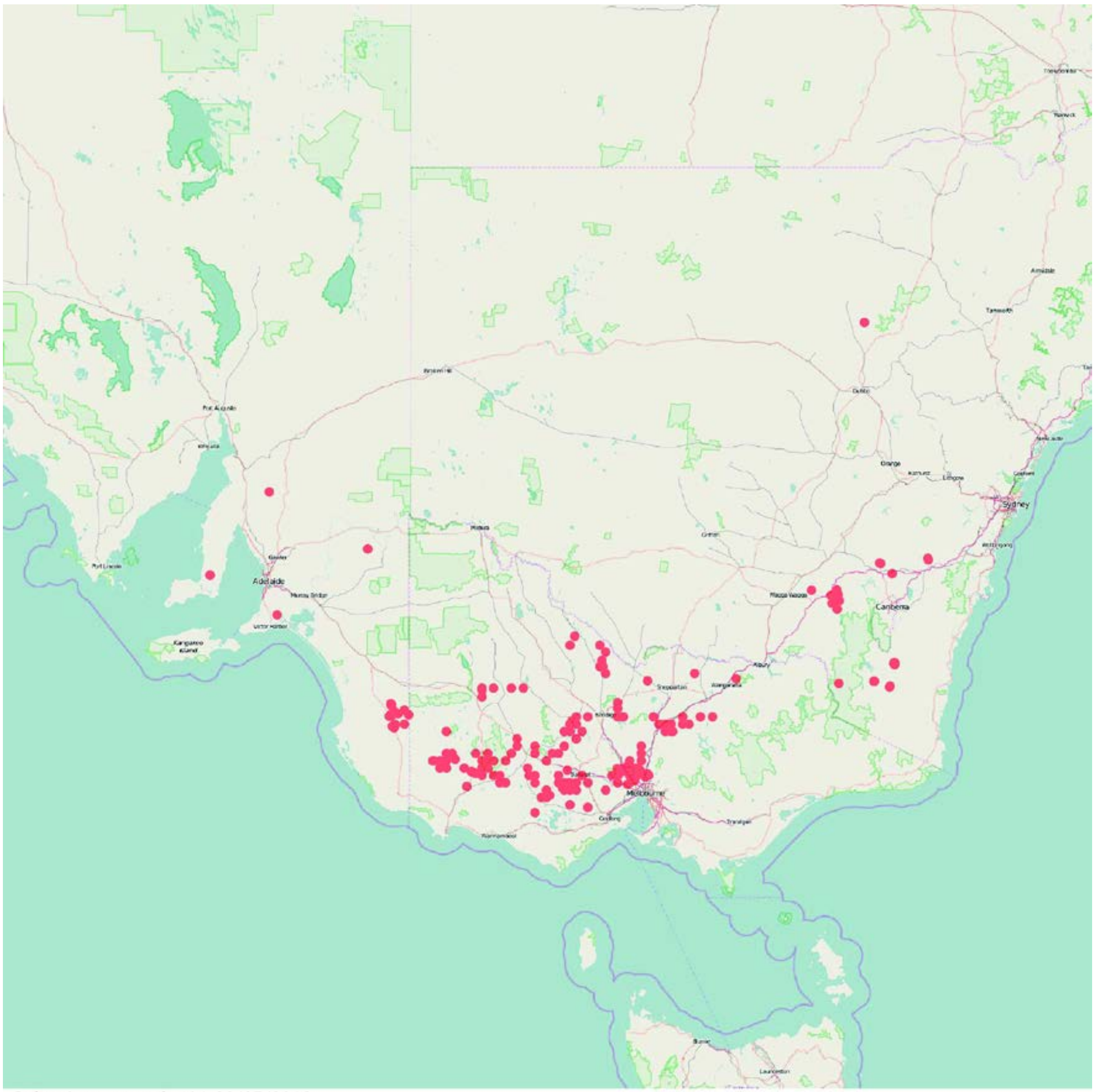
2.1 Striped legless lizard (Delma impar)

2.1.1 Biology

The striped legless lizard (*Delma impar*) is a semi fossorial reptile of the pygopodidae family, the legless or flap footed lizards, occurring in grasslands of South-Eastern Australia. The species has a maximum snout to vent length of 120 mm, full body length of 300 mm and weighs 8 grams (Robertson and Smith, 2010). It is diurnally active, foraging on the surface during the day and sheltering in soil, litter and grass tussock bases during the night (O'Shea, 2005).

2.1.2 Distribution

Delma impar is distributed across South-Eastern Australia in the ACT, NSW, Victoria and SA (Figure 2) (Robertson and Smith, 2010). In the ACT, *D. impar* is currently found in 4 isolated areas: Gungahlin, Majura Valley, Jerrabombera Valley and Yarramundi Reach with the Gungahlin area considered a stronghold for the species (ACT Government, 1997). *D. impar* was recorded near Cooma on the Monaro tablelands of NSW as of 1996 (Dorrough *et al.*, 1996). The species has been recorded from nearby areas of NSW (Goulburn, Yass and Monaro) and relatively large populations occur in Victoria and South Australia (Robertson and Smith, 2010).



Delma impar records ALA 20/05/2016

Figure 1. Delma impar distribution from Atlas of Living Australia (2016).

Note the atlas is not a complete record of all *D. impar* observations and some areas where *D. impar* occur may not be shown (for example, the ACT).

2.1.3 Habitat requirements

2.1.3.1 Floristics

D. impar are found predominantly in natural temperate grassland remnants but have been recorded occupying degraded native and exotic grasslands and secondary grasslands (cleared woodlands) within 2km of the historic distribution of natural temperate grassland (Robertson and Smith, 2010). *D. impar* have been recorded most commonly in grasslands with a dense cover of native perennial tussock forming grasses (Coulson, 1990). In the ACT, *D. impar* densities are highest in sites with a dense cover of spear grass (*Stipa bigeniculata*) or kangaroo grass (*Themeda triandra*) (Dorrough and Ash, 1999). However, they are not dependent on any plant species or community and have been recorded in grassland composed of a wide range of native and exotic grasses (Dorrough and Ash, 1999; Howland *et al.*, 2016). The species can reproduce in grasslands with a high component of exotic species such as serrated tussock

(*Nasella trichotoma),* Chilean needle grass (*Nasella neesiana)* and phalaris (*Phalaris aquatica)* (Robertson and Smith, 2010). However, no records could be found of the species living in African lovegrass (*Eragrostis curvula*). African lovegrass is a widely distributed invasive tussock grass introduced to Australia in the 1900's (Firn, 2009). It is difficult to control and has invaded native grasslands and pastoral land throughout South-Eastern Australia (Firn, 2009). It is a major component of derived grasslands at Scottsdale Reserve and may invade native grasslands throughout the region. Mixed African love grass and native pastures have recorded a high diversity and abundance of native reptiles, surpassing records of native dominated pastures in many cases (B Howland 2016, pers. Comm.).

2.1.3.2 Vegetation structure

D. impar and other legless lizards appear to selectively use habitat with a complex grass structure (mix of short and tall grass tussocks) (Howland *et al.*, 2016; Brown *et al.*, 2011{Dorrough, 1999 #20)}. A principal component analysis (comprising grass height, cover and biomass) had an optimal parabolic relationship with *D. impar* occupancy (Howland *et al.*, 2014) implying an optimal level of biomass, grass cover and height above which habitat value declines. Land use history and lack of previous disturbance to vegetation structure through overgrazing or ploughing appear to be more important in determining the species presence and abundance rather than an area's floristics (Dorrough and Ash, 1999). Areas with heterogeneous grass structure may provide diverse microhabitats necessary such as open areas for obtaining body warmth (Hacking *et al.*, 2014{Valentine, 2007 #134)} and foraging for prey (Bateman and Ostoja, 2012) and dense grass for shelter from summer heat (Sato *et al.*, 2014), refuge from predators (Sato *et al.*, 2014). Very short grass, which may occur due to overgrazing provides low quality habitat due to a lack of shelter from heat, predators and overwintering sites (Howland *et al.*, 2016).

2.1.4 Threats

Populations of *D. impar* are threatened by habitat loss, modification and degradation driven by urban development and intensive land management. Threatening processes include overgrazing, pasture improvement, ploughing and inappropriate fire regimes (Robertson and Smith, 2010; ACT Government, 1997). The natural temperate grasslands ecological community that *D. impar* are most often found in is listed as endangered on the Commonwealth EPBC Act (Environment ACT, 2005).

However, loss of areas where *D. impar* occur due to urban development is the most important current threat to the species in the ACT and results in 'doomed' populations.

2.1.5 Movement

D. impar were recorded moving an average of 5 metres in one day, up to 20 metres in one day (Kutt, 1993) and at most 60 m over two days (Kukolic *et al.*, 1994). However, these movements are not considered representative of regular movements (Robertson and Smith, 2010). O'Shea (2005) recaptured lizards over a period of 18 months under the same tile they were originally captured under 30% of the time where tiles were 2.5 m apart suggesting small home ranges. The average straight line movement distance between capture and recapture was 4.0 m. The home range of individuals is conservatively estimated at 10 m^2 (Robertson and Smith, 2010).

Historic land use, time since habitat disturbance and distance from undisturbed natural temperate grassland are important predictors of presence and abundance of *D. impar* in grasslands that appear to contain suitable habitat (Dorrough and Ash, 1999). Dispersal of *D. impar* is estimated at approximately 12 m/year, calculated from an estimated expansion of 2 km in 170 years. Dispersal appears limited by bare ground and roads and subsequently even if suitable habitat re-occurs in an area, *D. impar* are unable to recolonize.

2.1.6 Diet

D. impar are selective arthropod feeders exhibiting a sit-and-wait and active prey foraging strategy (Nunan, 1995). Studies in the A.C.T and South-West Victoria found their diet comprises mostly spiders, lepidoptera larvae, crickets and cockroaches (Nunan, 1995; Kutt *et al.*, 1998).

2.1.7 Temperature preference

Reptiles being ectotherms must obtain heat from their environment for physiological processes to occur. *Delma impar* is mostly thigmothermic (obtaining heat by conduction) but displays heliotermic behaviour (using radiant heat) (O'Shea, 2005).

D. impar mean preferred environmental temperature was 26.0 °C ± 1.5 (standard deviation, N=15) when exposed to a thermal gradient in a laboratory (Osmond, 1994). Osmond (1994) observed lizards choosing temperatures between 24.5 and 27.5 °C 70% of the time though lizards were active in a wide range of environmental temperatures. The mean preferred environmental temperature of *Anniella pulchra*, a fossorial legless lizard in the USA, was 23.6 °C ± 3.1 (standard deviation, N=96) when tested in a thermal gradient (Bury and Balgooyen, 1976).

The inability of reptiles to cool themselves means they must retreat to thermal refugia if environmental temperatures exceed critical maximum body temperature. Frequent high environmental temperatures may therefore result in a short activity period. For *D. impar* in the ACT, dense tall grass is likely to provide refugia and may be critical for the species persistence.

2.2 Translocation

2.2.1 Definitions

Translocation is defined as the human mediated movement of living organisms from one area, with release in another (IUCN/SSC, 2013). Three types have been defined: introduction, reintroduction and reinforcement. Reintroduction occurs where organisms are released into parts of their historic range from which they have become locally extinct. Introductions are releases of organisms outside their historic range, to expand the extent of occurrence of a species or to restore an ecological function that has been lost. Reinforcement is the release of organisms into an existing population of conspecifics (Seddon *et al.*, 2014).

Translocation has been used to increase the number of populations of a threatened species, establish populations in areas where a species has been made extinct, increase genetic diversity of isolated populations, provide ecological function to an ecosystem that has been lost, move species that cannot move fast enough as climate changes and relocate individuals from human-wildlife conflicts (Fischer and Lindenmayer, 2000; Germano and Bishop, 2009).

2.2.2 History

The use of translocation has expanded dramatically since 1990 (Armstrong and Seddon, 2008) and occasionally gained a high profile (Parker, 2008). Many successes have occurred, for example the North-East saddleback bird in New Zealand (Lovegrove, 1996), small mammals in Australia (Short and Turner, 2000; Richards and Short, 2003; Moseby *et al.*, 2011) and lizards on Caribbean islands (Fitzgerald *et al.*, 2015). However, the effectiveness of translocation as a conservation measure has been questioned in the context of limited funding for conservation and frequently low rates of success (Pérez *et al.*, 2012).

International reviews of translocation of all fauna groups have generally concluded translocations have high rates of failure (Fischer and Lindenmayer, 2000; Dodd and Seigel, 1991; Griffith *et al.*, 1989; Short, 2009). A review of published scientific journal articles on Australian species relocation programs found a success rate of 46%, of 25 programs assessed (Sheean *et al.*, 2012).

An early international review of 25 reptile and amphibian translocations found 19% of projects were successful, 58% had uncertain outcomes and 23% were unsuccessful (Dodd and Seigel, 1991). A 2009 review of 91 translocation projects published in the scientific literature after 1991 found 42% of reptile and amphibian translocations reviewed were classified as successful, 29% had uncertain outcomes and 28% were unsuccessful (Germano and Bishop, 2009). A review analyzing the success rate of published and unpublished herpetofaunal translocations in New Zealand found the actual rate of success (8%) was much lower than the rate of success within published translocations (42%), with uncertain outcomes more common (Miller *et al.*, 2014). Thus, the literature on biased towards successful projects. Standardised rates of success (47%), taking into account the species life history and time since translocation, were higher than rates of failure (20%) suggesting translocation may be a useful conservation action if appropriately planned (Miller *et al.*, 2014).

These compare to a success rate of 46% for threatened mammal and bird translocations reviewed in 1989 (Griffith *et al.*, 1989).

2.2.3 General principles

Reviews of translocation programs have recommended that success is more likely with large numbers of founder individuals (>100), wild caught individuals over captive reared, projects where the causes of initial decline have been removed, release sites are in the centre of historic range and contain high quality habitat (Fischer and Lindenmayer, 2000{Griffith, 1989 #64)}. Soft releases, the provisioning of assistance measures, did not consistently increase translocation success (Fischer and Lindenmayer, 2000).

The importance of long term monitoring of translocated populations and communication of positive and negative findings has been emphasized repeatedly (Fischer and Lindenmayer, 2000; Griffith *et al.*, 1989; Dodd and Seigel, 1991; Germano and Bishop, 2009).

Common reasons for failure include poor habitat quality at the release site, inadequate knowledge or control of the cause of decline, lack of predator control, environmental factors and poor management (Sheean *et al.*, 2012; Dodd and Seigel, 1991). Reptile translocation failures have been due to homing and dispersal, insufficient numbers, predation, food limitation and disease (Germano and Bishop, 2009).

2.2.4 Mitigation translocation

Mitigation translocation is the translocation of individuals to mitigate human-wildlife conflict, for example urban development (Germano *et al.*, 2015). Of all types of translocation, mitigation translocation has the highest rate of failure (Fischer and Lindenmayer, 2000; Germano and Bishop, 2009). These fail to follow scientific best practice, are often conducted with little planning, consideration of the species biology and behaviour and are poorly documented (Germano *et al.*, 2015). The IUCN '*Guidelines for Reintroductions and Other Conservation Translocations*' considers mitigation translocations separately to conservation translocations as mitigation translocations concern the welfare of individual animals rather than populations of species (IUCN, 2013). Germano et al. (2015) referring to mitigation translocations wrote:

> *"This raises the question of whether such animals are simply being spared a socially unacceptable death via bulldozer only to perish out of view at a release site or whether the translocations are a useful tool, wisely applied to minimize the effects of humans' actions on imperiled wildlife."*

Knowledge of the ecology, behaviour, sociality and habitat requirements of the target species, identification of knowledge gaps, and anticipation of potential outcomes based on studies of other taxa is required for successful mitigation translocation, as in conservation translocations (Sullivan *et al.*, 2015). Mitigation translocations is often warranted where entire habitats are being destroyed by urban development (Sullivan *et al.*, 2015). Sullivan *et al.* (2015) recommend reviewing previously conducted studies and conducting planning based on life history, behaviour and critical habitat features of target species. The small number of mitigation translocations of herpetofauna considered successful conducted through pretranslocation planning resulting in improved survival and persistence of translocated individuals (Sullivan *et al.*, 2015). A review of herpetofaunal translocations in New Zealand found no difference in rates of success and failure of translocations conducted for conservation, research or mitigation purposes (Miller *et al.*, 2014).

2.2.5 Reptile translocation

Reptiles and amphibians are generally suitable candidates for conservation translocation programs due to high fecundity, lack of parental care and that numerous species can be bred in captivity in a cost effective way (Germano and Bishop, 2009). A taxonomic bias towards mammals and birds occurs in translocations conducted (Seddon *et al.*, 2005; Bajomi *et al.*, 2010; Fischer and Lindenmayer, 2000). Reptiles, amphibians and invertebrates comprised 7% and mammals and birds 93% of translocations assessed in an international review (Fischer and Lindenmayer, 2000). Very few reptile translocations with published results have occurred in Australia (Short, 2009). The only reptile to have been translocated multiple times is the Western swamp tortoise. Due to the longevity of the species, translocation outcome is uncertain (Short, 2009).

Published reptile translocations include successes, for example skinks in the USA, lizards in Caribbean islands (Dickinson *et al.*, 2001; Fitzgerald *et al.*, 2015) and chameleons in South Africa (Armstrong, 2008), failures, for example slow worms in the UK (Platenberg and Griffiths, 1999) and pythons in Australia (Read *et al.*, 2011), and projects with uncertain outcomes, for example skinks in NZ (Towns and Ferreira, 2001).

2.2.6 Striped legless lizard translocation

Translocation has been identified as a conservation action for *D. impar* since at least 1995 (Coulson, 1995; Nunan 1996; Dorrough & Ash, 1999). Researching the feasibility of translocation is one of the objectives in the national recovery plan (Robertson and Smith, 2010). The plan states that useful information on habitat requirements can be learnt by conducting a translocation, especially one set-up as an experiment. Various poorly documented trial translocations have occurred in Victoria with lizards salvaged from grasslands prior to urban development. The persistence of animals released into enclosures was high (between 67 and

75% of individuals recaptured) five years after release though almost no animals released into unfenced areas were recaptured in post release monitoring (Parks Victoria, 2002). Translocation of breeding individuals to suitable habitat may be a desirable conservation strategy to increase the number of populations due to the inability for *D. impar* to disperse long distances or across barriers (Dorrough and Ash, 1999).

Translocation of a functionally similar species (USA sand skink *Plestiodon reynoldsi*) occurred in an experimental setting with treatments applied at the release site in response to uncertainty on habitat requirements (McCoy *et al.*, 2014). Habitat heterogeneity was an important factor in release areas where translocation was successful.

2.3 Summary

D. impar populations are likely to continue to be lost due to urban development (O'Shea, 2013). Isolated populations do not naturally interbreed and areas of unoccupied suitable habitat will not be colonized naturally (Dorrough and Ash, 1999). The value of translocation as a measure to reintroduce the species to suitable unoccupied habitat patches or mitigate impacts of urban development is not known. Translocation tactics and biophysical factors required at a release site to increase the likelihood of successful translocation for this species have not been rigorously experimentally tested.

African lovegrass is a major component of grasslands at Scottsdale Reserve and may invade grassland reserves throughout South-Eastern Australia. An investigation of its value as *D. impar* and other grassland reptile habitat is critical to be able to conduct scientifically supported grassland conservation management. *D. impar* are known to occur in high complexity grass (a mix of short and tall grass), however the drivers of this habitat choice are not known. Research on other reptile suggests opportunities for thermoregulation (Hacking *et al.*, 2014; Downes and Hoefer, 2007) , shelter from extreme heat (Sato *et al.*, 2014{Price, 2010 #131), food availability (Bateman and Ostoja, 2012; Price *et al.*, 2010), lower predation risk (Sato *et al.*, 2014; Price *et al.*, 2010), shelter (Hitchen *et al.*, 2011), connectivity and dispersal (Price *et al.*, 2010) and ease of movement (Rieder *et al.*, 2010) may be potential reasons.

Thus, this project had three aims

1. Determine the suitability of Scottsdale Reserve as a *D. impar* translocation release site by comparing relevant biophysical factors at Scottsdale to the source site which was a high quality site (reference) due to high *D. impar* density.
2. Investigate microhabitat use of *D. impar* in relation to vegetation composition and structure, invertebrate prey and thermal conditions to determine the factors driving *D. impar* habitat preferences in native and exotic grasses.

3. Determine the degree of initial persistence and ability to recapture translocated *D. impar* during two months after translocation to provide an early indication of whether the translocation may be successful in the long term.

Chapter 3: Methods

3.1 Introduction

Translocations and mitigation translocations in particular have had a high rate of failure in the literature (Germano *et al.*, 2015). Reasons for failure are considered to be poor planning and frequent lack of consideration of the species biology (Germano *et al.*, 2015). This translocation aimed to address these issues by conducting extensive planning across agencies with the Australian National University, Bush Heritage Australia and ACT and NSW government. Bush Heritage Australia were looking to reintroduce *D. impar* to their Scottsdale Reserve following extensive monitoring that identified the absence of the species despite potential habitat (B Howland 2015, pers. comm.). Bush Heritage Australia then partnered with the ACT government, at which time two suitable *D. impar* source sites were identified as they contained populations ‘doomed’ due to urban development.

The experimental design of the translocation was peer reviewed by experienced ecologists from the Australian National University Fenner School and Bush Heritage Australia. A translocation plan created by a consultant to Bush Heritage Australia was submitted to the NSW Office of Environment and Heritage, reviewed by two experts (including Professor Will Osborne an expert on the biology of the species) and accepted. Approval was obtained from the Australian National University animal ethics committee and licenses from the ACT government to take and release animals and from the NSW government to conduct an experimental translocation were obtained.

This translocation has adhered to recommendations from international reviews (Fischer and Lindenmayer, 2000{Germano, 2009 #10; Germano *et al.*, 2015; Sullivan *et al.*, 2015) for translocations to be thoroughly planned, informed by detailed biological and life history information on the species and conducted by interdisciplinary teams in both conservation and mitigation translocation projects. Further, the *D. impar* national recovery plan (Robertson and Smith, 2010) states an experimental translocation of the species can be a useful conservation action.

3.2 Study Sites

D. impar were sourced from two urban development sites in Gungahlin, ACT (Old Wells Station Rd, Kenny and Mullangarri Grasslands, Flemington Rd, Figure 4). Sites are 4.5 kilometres apart and no obvious features exist that would have prevented the sites being connected by contiguous grassland prior to urbanisation. Previous land-use was horse grazing and one site was managed as future urban development land. Grass was a variety of native and exotic perennial and annual grasses.

D. impar were released at Scottsdale Reserve, a 1328 ha property near Bredbo (Monaro Tablelands, NSW, Figure 3) owned and managed by Bush Heritage Australia. Parts of the property have been cleared, cropped, ploughed and heavily grazed. Overgrazing in previously ploughed and pasture improved areas resulted in large areas of bare ground that were colonised by the invasive grass African lovegrass (*Eragrostis curvula*). The valley floors are currently almost entirely dominated by African lovegrass. Areas that were too rocky to be ploughed retained native grasses and are currently dominated by the native kangaroo grass (*Themeda triandra*).

Areas of Scottsdale are likely to have contained natural temperate grassland prior to intensive agricultural use of the land. These grasslands were likely to have been contiguous with extensive natural temperate grasslands on the Monaro plains where populations of *D. impar* remain today (Dorrough *et al.*, 1996). Thus *D. impar* are considered likely to have occurred at Scottsdale Reserve in the past and suitable habitat (a mix of short and tall dense perennial tussock grasses) currently appears to occur at the reserve (B Howland 2015, pers. comm.). Regular reptile surveys over the past 5 years have shown a high diversity and abundance of reptiles (B Howland 2015, pers. comm.) in the grassland areas including in African lovegrass, however *D. impar* has never been recorded and is unlikely to be present. These factors suggest an experimental translocation of *D. impar* to Scottsdale Reserve testing habitat preference is a useful conservation action for the species.

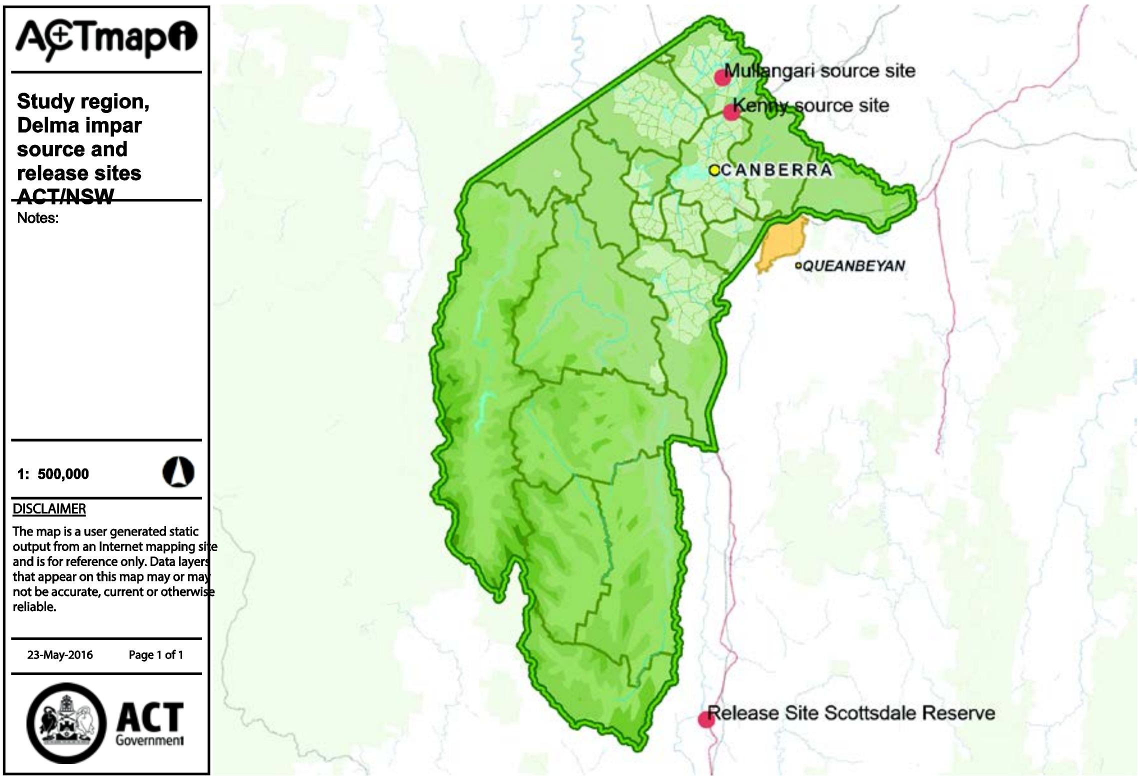


Figure 2. Map of the study area showing source and release sites. EPIC release site is referred to as Kenny release site on this map.

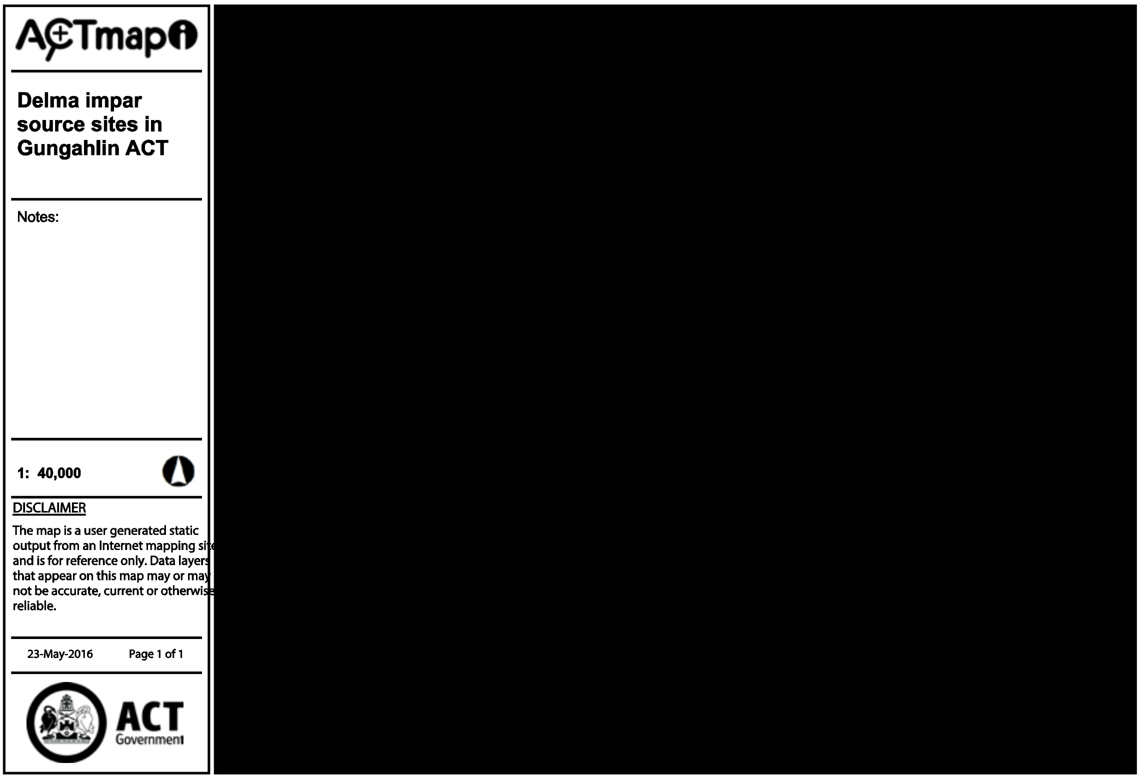


Figure 3. Detailed map of source site region, Gungahlin ACT. EPIC release site is referred to as Kenny release site on this map.

3.3 Experimental design

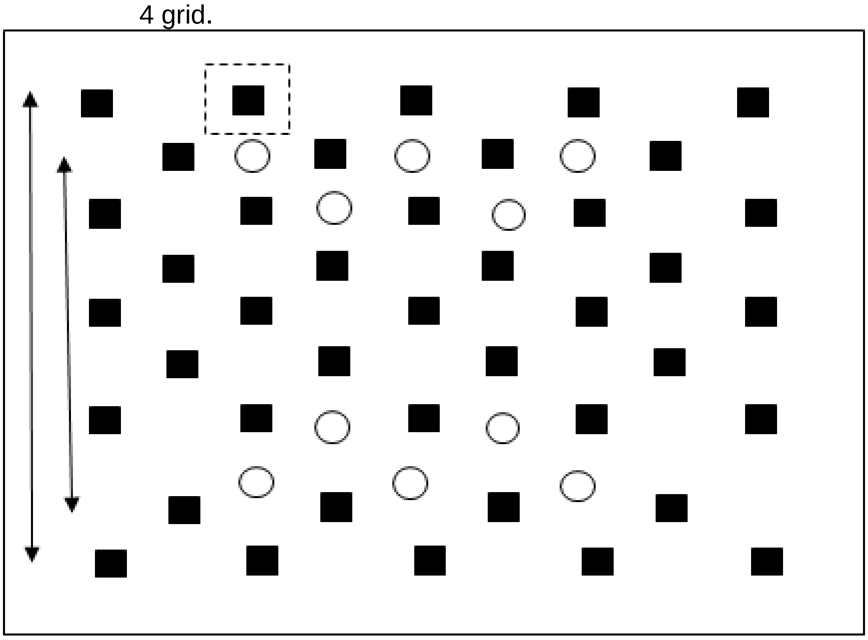
To increase the number of animals captured, *D. impar* were sourced from two sites (figure). Animals were captured in October 2015 using grids of concrete roof tiles as artificial reptile micro-habitats. Grids were composed of 25 tiles arranged in 5 rows of 5 (5 x 5) with tiles 5 metres apart. Concrete tiles are effective at detecting and capturing this species due to heat that accumulates under tiles. Lizard use tiles for thermoregulation when they require heat to enable activity (Michael *et al.*, 2012; O'Shea, 2005; Thompson, 2006). Approximately 15 tile grids were established per site and grids were relocated when *D. impar* stopped being captured indicating most or all individuals had been removed from the location.

Animals were released at one site into four *D. impar* proof fenced enclosures 900 m^2 in area (30x30m) and four unfenced plots. Sites were chosen to contain approximately 50% African lovegrass and 50% kangaroo grass dominated areas with the transition area between the grass types a mix of the grasses. Fenced enclosures are useful for preventing dispersal, increasing site fidelity and increasing capture rate for *D. impar* (oshea) and other reptiles (Knox and Monks, 2014; Fitzgerald *et al.*, 2015) Roe 2010). Monitoring five years after translocation resulted in a high proportion of recaptured *D. impar* in enclosures but almost no recaptures at open release sites (Parks Victoria, 2002). Enclosures were therefore considered essential for this translocation, thus the release was a soft release. Each enclosure contained 41 tiles arranged in one 5 x 5 grid and one 4 x 4 grid within the 5 x 5 grid. Tiles were approximately 2.5 metres apart (figure) and numbered.

The four unfenced release plots had a larger tile grid (eight rows of eight tiles spaced five metres apart) to detect *D. impar* dispersal. The four unfenced release plots were not monitored as this study focused on suitability of the release site for *D. impar*, short term persistence and habitat use and intensively surveying enclosures answered these questions more effectively.

Figure 4. Schematic diagram of release enclosures.

Squares indicate tiles, circles indicate invertebrate pitfall traps and dotted square indicates the 1 m^2 quadrat placed around each tile andd trap for vegetation survey. The long arrow indicates the five rows of tiles making up the 5 x 5 grid and the short arrow indicates four rows making up the 4 x 4 grid.



3.4 Lizard capture and release

3.4.1 Capture

Tiles at capture sites were turned between once and three times per week and animals captured by hand. Animals were kept individually in cloth bags in a dark cool box and released on the same day as captured. Lizard capture, captivity and release protocols were as approved in scientific license SL101625 from the NSW Office of Environment and Heritage and ANU Animal Ethics approval A2015_31.

3.4.2 Release

Twelve *D. impar* were released into each enclosure resulting in a density of 133 lizards/Ha, comparable to the highest densities recorded at the source site (source site highest small scale density >155/Ha, B Howland 2015, pers. comm). To ensure all enclosures were filled at the same time, one quarter of *D. impar* on each release day were released into each of the four enclosures. Filling each enclosure with 12 *D. impar* was completed on approximately the same day in each enclosure. Prior to release, animals were marked, measured and photographed to record head scale patterns. These were later used to identify recaptured lizards using the methods in (O'Shea, 2005).

3.4.3 *Delma impar* monitoring/surveying

I conducted ten visits to each grid to survey *D. impar* between October and December 2015. Surveys began nine days after the last animal was released to allow *D. impar* to select habitat. Surveys occurred between 7:00 and 11:00am and opportunistically at other times when conditions appeared suitable (cool temperature between 15 and 25 °C, cloud cover or rain). During each survey, enclosures were checked in a random order and all tiles in a grid were turned. On one occasion, conditions appeared to be suitable for *D. impar* surveying late in the day. Two grids were checked only as it then became too late for captures to be likely by the time two grids were checked. On another occasion, two grids were checked in suitable conditions with conditions then becoming too hot and the remaining two grids not checked.

When a *D. impar* was detected, the tile, enclosure, time, air temperature at the nearest weather station (Cooma Airport 47 kilometres away, weather station number 070217), cloud cover on a 4 point scale (none, partial <50%, >50%, completely overcast) and descriptors of morphology (colouring, striping, tail loss, evidence of gravidity) were recorded. The mark (if it was visible) was recorded and a photograph of the head was taken to identify lizards by matching head scale patterns to photos taken prior to release. Detections included seeing a lizard but not capturing it and seeing a shed skin under a tile. Skins were removed from under tiles to avoid double counting.

3.5 Site comparison

3.5.1 Vegetation and habitat

Vegetation at source and release sites was compared to determine whether vegetation at the release site would provide suitable habitat. The EPIC source site had a high density of *Delma impar* compared to other sites in the ACT (B Howland 2015, pers. comm.) and the existing vegetation species and structure were therefore assumed to provided suitable *D. impar* habitat.

Vegetation characteristics thought to be important components of *D. impar* habitat were measured in 1 m^2 quadrats. At both the source and release sites, ten quadrats was placed per grid in four *D. impar* capture grids (one quadrat around each of ten invertebrate traps). Grass height was measured in the four quarters of the quadrat as the average of leaf height in each quarter. Quadrat average leaf height and variance in height were calculated. A measure of grass structural complexity was made following Brown *et al.* (2011) and {Howland, 2016 #140@@author-year using the formula Complexity = Ln(mean grass height * grass height variance).

The dominant grass species (African lovegrass, kangaroo grass or mixed composition grass [between 40-60% African lovegrass and 40-60% kangaroo grass]) and percentage of ground cover (5 categories: 100-80%, 80-60%, 60-40% etc.) were visually estimated in each 1 m^2 quadrat. Forty vegetation survey quadrats were conducted at both source and release sites.

Ground cover data for the release site was obtained from quadrat surveys around each tile in release enclosures (not around each invertebrate trap as above) due to ground cover data not being collected around invertebrate traps.

3.5.2 Invertebrates

Invertebrates were surveyed to establish differences and similarities in *D. impar* food availability between source and release sites.

Invertebrates were surveyed using pitfall traps, as this technique is effective at sampling small ground dwelling invertebrates including spiders, crickets and cockroaches that are a large component of *D. impar* diet in the A.C.T {Nunan, 1995 #18}. Pitfall traps were made of 9 cm diameter cups dug into the soil with the top of the cup level with the soil surface. Pitfall traps contained glycol to attract invertebrates, as an invertebrate preservative and because it does not evaporate. Methylated spirits was added to deter kangaroos from drinking glycol. Pitfall traps were open at both sites in November within a day of each other and kept open for 2 weeks. Invertebrates trapped were classified to family level and the number of individuals in invertebrate families described as *D. impar* prey, spiders, crickets and cockroaches, (Nunan, 1995) were counted. Due to low capture rates at both sites (n=4) cockroaches were not considered in the analysis leaving only spiders and crickets for analysis.

Ten pitfall traps were placed per grid in four grids at both source and release sites. At the release site, five traps were placed in each of African lovegrass and kangaroo grass areas. Traps were placed systematically to ensure thorough coverage of both grass communities and were placed in locations where a single grass type occurred within 1 metre of the trap. Twenty traps were placed in African lovegrass and 20 in kangaroo grass at the release site. Forty pitfall traps were placed at both source and release sites.

Average height and structural complexity around pitfall traps was measured and calculated as for vegetation surveys.

Three traps from the source site (EPIC) were excluded from the analysis. This was due to being unable to find one trap in the field, preservative liquid evaporating from one trap (thus invertebrates were able to escape) and one trap that contained no invertebrates or soil and appeared to never have been placed in the field.

3.5.3 Temperature

Reptiles are unable to regulate their body temperature and rely on behaviour and external sources of heat or shade to maintain body temperature within a range allowing physiology (Spellerberg, 1972). High environmental temperatures may be harmful to *D. impar* as they are unable to cool their body. Therefore high temperature may influence habitat selection and population persistence. Ground temperature in early summer was monitored to determine if and for how long ground temperatures exceeded *D. impar* critical maximum body temperature between sites and grass types. Forty °C was used as the critical maximum body temperature. This is the critical maximum body temperature of the little whip snake (*Suta flagellum*) (Spellerberg, 1972). It was used due to a lack of data on *D. impar* as both species inhabit grasslands, are sympatric (co-occur at sites), thigmothermic and have relatively similar length and weight (Cogger, 2014; Bennet, 2011; OEH, 2015).

To measure ambient ground temperature, four temperature loggers (Thermochron i-Buttons, Thermodata Pty Ltd) were placed in each enclosure at the release site with half placed in African lovegrass and half in kangaroo grass. Four temperature loggers were placed in each of the same four grids at the source site as for invertebrate trapping to compare thermal conditions at the release and source sites. Eight loggers were placed in African lovegrass and eight in kangaroo grass at the release site. Sixteen temperature loggers were placed at each site. Loggers were placed in contact with the ground, partially shaded by a grass tussock and on the South side of a tussock to ensure they were shaded for the longest time as sun temperatures will not be comparable between loggers.

Grass height and ground cover around loggers was assessed using the same method as for vegetation surveying around invertebrate traps.

Loggers recorded data from 21:00 on 8 December until 23:59 on 21 December. Ten temperature loggers were excluded from the comparison analysis. One logger malfunctioned, one was lost in the field and the precise placement in the field of six was unknown due to poor data recording. Eight loggers in kangaroo grass and six loggers in African lovegrass remained with useable data. To ensure non biased sampling of the release site (Scottsdale), two loggers in kangaroo grass chosen at random were excluded from the between site comparison. A random number between 1 and 8 was assigned to each logger. Then two random numbers between one and eight were generated and the loggers with matching numbers were chosen.

3.6 Release site grass comparison

3.6.1 Vegetation and habitat

Habitat at the release site was sampled using 1 m^2 quadrats around each survey tile in the four enclosures (total 164 quadrats) from November X to December X. In each quadrat, a selection of habitat variables with known association to habitat selection by *D. impar* were chosen. These included: dominant grass species, average grass leaf height, grass structural complexity, percentage ground cover (5 categories: 100-80%, 80-60%, 60-40% etc.) and rock cover (4 categories: 0%, <5%, 5-20%, 20-40%). Variables were recorded and calculated using the same methods as in vegetation surveys for the between site comparison. Due to equal height measurements used to calculate the mean grass height, grass complexity could not be calculated for two observations as the variance in height was 0. These observations were excluded from the complexity dataset.

3.6.2 Invertebrates

Invertebrates were surveyed to establish differences and similarities in *D. impar* food availability between African lovegrass and kangaroo grass and determine the suitability of African lovegrass and kangaroo grass at Scottsdale as habitat for *D. impar*. Pitfall traps used for site comparisons were also used for the grass type comparison with methods explained in section 3.5.2: Invertebrates.

3.6.3 Temperature

Ground temperature was surveyed to determine differences in the number of hours ground temperature exceeded lizard critical maximum body temperature in African lovegrass and kangaroo grass and determine the suitability of African lovegrass and kangaroo grass at Scottsdale as habitat for *D. impar*. Temperature loggers used for site comparisons were also used for the grass type comparison with methods explained in section 3.5.3: Temperature.

3.7 Habitat use

D. impar occurrence is greater in areas with high grass structural complexity, i.e. areas with a mix of short and tall grass (Howland *et al.*, 2016) but preference for grass type (species) is limited (Dorrough). I aimed to determine if released lizards had a preference for vegetation of a certain composition and structure. Habitat data around tiles collected for vegetation survey was used for the *D. impar* habitat use study. Data on habitat variables of the immediate environment around each lizard survey tile collected in the comparison of grass types vegetation survey was used for the *D. impar* habitat use study.

3.8 Initial persistence

D. impar identity was determined by looking for the coloured mark that had been made on released *D. impar* and comparing head scale patterns on lizard head photographs taken of *D. impar* recaptured at the release site to head photos taken of *D. impar* prior to release. This allowed the number of unique individuals recaptured at the release site to be determined. *D. impar* persistence was determined by calculating the percentage of *D. impar* individuals released that were recaptured at the release site during the two months of monitoring following release.

3.9 Statistical analysis

3.9.1 Habitat analyses

3.9.1.1 Vegetation

To test differences in average grass height and grass structural complexity between source and release sites and between grass types at Scottsdale (African lovegrass, kangaroo grass and mixed grass type) I used a hierarchical generalised linear model (HGLM). Average grass height and complexity were the response variates and were modelled with a normal distribution and identity link function. Site was included as the fixed effect (explanatory variable) and enclosure as the random effect modelled with a normal distribution and identity link function. Differences in ground cover and rock cover between sites and between grass types at Scottsdale were analysed with Pearson’s chi square test for independence as data was categorical. Where more than 20% of estimated occupancy frequencies were below five, Pearson’s chi square permutation test was used.

3.9.1.2 Invertebrates

To test differences in the number of individuals from *D. impar* invertebrate prey families trapped between sites and between African lovegrass and kangaroo grass at Scottsdale I used a HGLM. The response variate was number of invertebrates caught per trap and was modelled with a poisson distribution and logarithm link function. Site and grass type were included as the fixed effect (explanatory variable) and enclosure as the random effect modelled with a gamma distribution and logarithm link function.

3.9.1.3 Temperature

To test differences in the number of hours per day exceeding *D. impar* critical maximum body temperature between sites and between African lovegrass and kangaroo grass at Scottsdale I used a HGLM. The response variate was hours per day exceeding maximum body temperature and was modelled with a normal distribution and identity link function. Site and grass type were included as the fixed effect (explanatory variable) and enclosure as the random effect modelled with a normal distribution and identity link function.

3.9.2 Delma habitat use

The effect of vegetation variables at the tile scale (grass species, grass height and grass structural complexity surrounding tiles) on the probability of *D. impar* occupancy under tiles was modelled with hierarchical generalised linear modelling (HGLM). HGLM is useful when explanatory and response variables are non normally distributed and random effects may affect the response variate (such as tiles grouped in enclosures) (Bolker *et al.*, 2009). *D. impar* tile occupancy was modelled with lizard presence/absence data. Presence was defined as a tile recording at least one *D. impar* detection over the ten tile checks (absence was no detections).

The response variate was *D. impar* tile occupancy and was modelled with a binomial distribution and logit link function.

The interaction between grass type and structural complexity was included as the fixed effect (explanatory variable, ‘treatments’) to test whether preference for grass complexity was influenced by grass type. Grass type and structural complexity were correlated: low complexity grass was typically kangaroo grass and high complexity grass was typically African lovegrass. Thus, including grass type and grass complexity in the model as additive effects did not provide any more information than including only one of them in the model. As a result, the interaction between grass type and complexity was included as a fixed effect without each variable also included as an additive effect. Grass complexity was used preferentially to grass height as the formula for complexity contains average grass height and variance in grass height and is therefore more insightful than height on its own. Enclosure was included as a random effect due the tiles being grouped into enclosures. Environmental factors not measured may have affected tiles in some enclosures but not others (for example predation risk, soil conditions or aspect). Therefore, each tile was not equally independent of each other tile. The random effect was modelled with a beta distribution and logit link function. Table 1 shows an example of how analyses were structured in the statistical software. Continuous variables were standardised to have a mean of zero and standard deviation of one to allow comparison between variables. Standardisation involves subtracting the mean from each observation then dividing by the standard deviation.

Adding ground and rock cover surrounding tiles in the model as fixed terms did not produce better fitting models due to these variables being correlated with grass complexity and grass type. Therefore, these variables were not included in the final predictive model of *D. impar* occupancy.

Tiles lizards were released at were included in the habitat use dataset due to a nine day delay between the last release day and first recapture day allowing time for *D. impar* to select habitat. Tiles are only used for thermoregulation, not shelter, habitat or food provision and therefore *D. impar* are required to move from tiles each day. Lizards were observed at times moving more than 3 metres after initial release and when released after subsequent captures indicating they would have encountered more tiles than solely the one they were released under during their daily movements.

Mixed grass type was excluded from the analysis due to convergence issues when the category was included in the model due to a low number of *D. impar* detections and a low number of total tiles in mixed grass. Testing *D. impar* occupancy of mixed African lovegrass and kangaroo grass was also not the aim of the study.

The effect of grass height above the temperature logger and grass composition on number of hours per day exceeding critical maximum body temperature was modelled using a HGLM.

The response variate was hours per day exceeding critical temperature and was modelled with a normal distribution and identity link function. The interaction of near grass height and type was included as the fixed effect (explanatory variable) to test whether the effect of grass height was influenced by grass type and enclosure was included as the random effect modelled with a normal distribution and identity link function. Near grass height (the height of grass directly above the logger) was chosen as it was considered to be a truer explanatory variable for measured temperature rather than average grass height, or complexity as it is based on average grass height. The average grass height could have been high if surrounding grass was moderately tall despite grass directly above the logger being short, and ground temperatures therefore being very high.

The effect of grass structural complexity and grass composition on number of invertebrates caught per trap (spiders and crickets) was modelled using a HGLM. The response variate was number of invertebrates caught per trap and was modelled with a poisson distribution and logarithm link function. The interaction of grass complexity and type was included as the fixed effect (explanatory variable) to test whether the effect of grass complexity was influenced by grass type and enclosure was included as the random effect modelled with a normal distribution and identity link function.

Statistical analyses were conducted in Genstat 17 (VSN International 20XX).

Table 1. Example of the structure of *D. impar* hierarchical generalised linear models.

Hierarchical generalized linear model

Response variate: Lizard_presence_11Oct_removed

Binomial totals: 1

Mean model

Fixed terms: Complexity_standard.Dominant_grass_vegetation

Distribution: binomial

Link: logit

Random terms: Grid_Enclosure

Distribution: beta

Link: logit

Dispersion: free

Dispersion model

Distribution: gamma

Link: logarithm

Chapter 4: Results

4.1 Site comparison

I aimed to determine whether the release site, Scottsdale Reserve, was similar to the source site, EPIC, in vegetation structure, invertebrate prey abundance and thermal conditions to determine if the translocation is likely to be successful in the long term. The source site had a high *D. impar* density and is assumed to contain vegetation structure, invertebrate prey and thermal conditions characteristics suitable for long term survival of the species.

4.1.1 Vegetation

Vegetation at the source site (EPIC) was a mix of perennial exotic grasses (phalaris, *Phalaris aquatic*; Yorkshire fog, *Holcus lanatus*) and native (speargrass, *Austrostipa bigeniculata*) with exotic annual grasses (*Vulpia spp.*). The release site (Scottsdale Reserve) had areas dominated by either kangaroo grass (*Themeda triandra*) or African lovegrass (*Eragrostis curvula*).

Average grass height and grass structural complexity between the source (EPIC) and release site (Scottsdale) were not significantly different (p=0.65 and p=0.55 respectively, Table 2). Sites were different in groundcover proportion (p=0.008). All vegetation survey quadrats at EPIC contained between 80-100% groundcover. The majority (80%) of quadrats at Scottsdale had groundcover in the 80-100% category, however 20% contained groundcover of less than 80% (Table 4).

Table 2. Summary of vegetation variables between source (EPIC) and release (Scottsdale) sites.

Variable	Site	Average value	Standard deviation	N
Grass height	EPIC	11.0	3.9	40
	Scottsdale	10.1	5.0	40
	Statistic result	Wald statistic=0.20, p=0.65		
Grass structural complexity	EPIC	4.3	1.1	40
	Scottsdale	4.0	2.1	40
	Statistic result	Wald statistic=0.36, p=0.55		

Table 3. Percentage of quadrats in ground cover categories between source (EPIC) and release (Scottsdale) sites.

Variable	Description	Category	EPIC (source)	Scottsdale (release)
Ground cover	Percentage of tiles in category (%)	3: 40-60%	0	12
		4: 60-80%	0	9
		5: 80-100%	100	80

		Total number of tiles	40	164
	Statistic result	$X^2=9.6$, p=0.01		

4.1.2 Invertebrates

The mean number of orthoptera (crickets, grasshoppers, locusts and related organisms) per trap was not significantly different (p=0.94) between EPIC and Scottsdale Reserve (Table 4). The mean number of araneae (spiders) per trap was nearly significantly higher (p=0.067) at EPIC than Scottsdale (Table 4).

Table 4. Invertebrate captures per trap between source (EPIC) and release (Scottsdale) sites.

Variable	Site	Average captures	Standard deviation	N
Crikets	EPIC	3.60	3.0	37
	Scottsdale	3.63	3.87	40
	Statistic result	Wald statistic=0.005, p=0.94		
Spiders	EPIC	5.68	4.33	37
	Scottsdale	3.38	2.27	40
	Statistic result	Wald statistic=3.36, p=0.067		

4.1.3 Temperature

The mean number of hours per day ground temperature exceeded the critical maximum body temperature (40 °C) of a sympatric species (*Suta flagellum*, Little-whip snake) was significantly higher (p=0.004) at EPIC than Scottsdale (Table 6).

Table 5. Hours per day ground temperature exceeded lizard critical maximum body temperature of 40 °C between source (EPIC) and release (Scottsdale) sites.

Variable		Mean	Standard deviation	N
Hours per day over 40 °C	EPIC	4.602	1.544	10
	Scottsdale	2.345	2.090	14
	Statistic test	Wald statistic=8.287, p=0.004		

4.2 Release site grass comparison

I aimed to determine whether African lovegrass and kangaroo grass at the release site, Scottsdale Reserve, contained suitable vegetation structure, invertebrate prey abundance and thermal conditions to determine if they could provide suitable *D. impar* habitat.

4.2.1 Vegetation

Average grass height and grass structural complexity were significantly higher in African lovegrass followed by mixed grass type then kangaroo grass (p<0.001 and p<0.001 respectively, Table 6). Proportion of ground cover was unrelated to grass type (p=0.36) (Table 7).

Table 6. Grass height and grass structural complexity between African lovegrass (*E. curvula*), kangaroo grass (*T. triandra*) and mixed grass at Scottsdale.

Variable	Grass type	Average value	Standard deviation	N
Average grass height (cm)	African lovegrass	13.8	4.7	50
	Kangaroo grass	6.8	2.3	81
	Mixed	11.0	3.1	33
	Statistic result	Wald statistic=141.2, p<0.001		
Average grass structural complexity	African lovegrass	5.7	1.3	50
	Kangaroo grass	3.0	1.4	81
	Mixed	5.0	1.5	33
	Statistic result	Wald statistic=128.7, p<0.001		

Table 7. Percentage of quadrats in ground cover categories and in each grass type at Scottsdale (release site).

Ground cover	Percentage of tiles in category (%)		
	African lovegrass	kangaroo grass	mixed grass
3: 40-60%	18	9	9
4: 60-80%	10	6	12
5: 80-100%	72	85	79
Total number of tiles	50	81	33
Statistic result	X^2=4.39 , p=0.36		

4.2.2 Invertebrates

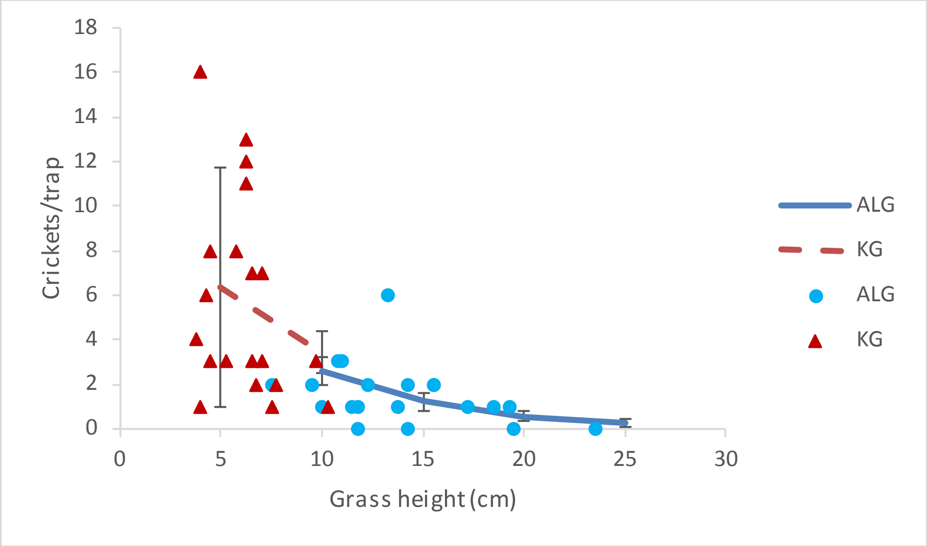
Cricket abundance per trap was significantly lower (p<0.001) in African lovegrass than kangaroo grass and spider abundance per trap was similar (p=0.838) between grass types (Table 8). Three cockroaches were captured in African lovegrass and one in kangaroo grass.

Cricket abundance per trap decreased with increasing grass height surrounding the trap (p<0.001, Figure 5 and Table 9). Spider abundance per trap was unrelated to grass height surrounding the trap in both grass types (Figure 5 and Table 9).

Table 8. Invertebrate captures per trap in African lovegrass (*E. curvula*) and kangaroo grass (*T. triandra*) at the release site.

Variable	Pasture community	Average value	Standard deviation	N
Crickets	African lovegrass	1.55	1.40	20
	Kangaroo grass	5.7	4.44	20
	Statistic result	Wald statistic=18.01, p<0.001		
Spiders	African lovegrass	3.45	2.61	20
	Kangaroo grass	3.3	1.95	20
	Statistic result	Wald statistic=0.042, p=0.838		

A)



B)

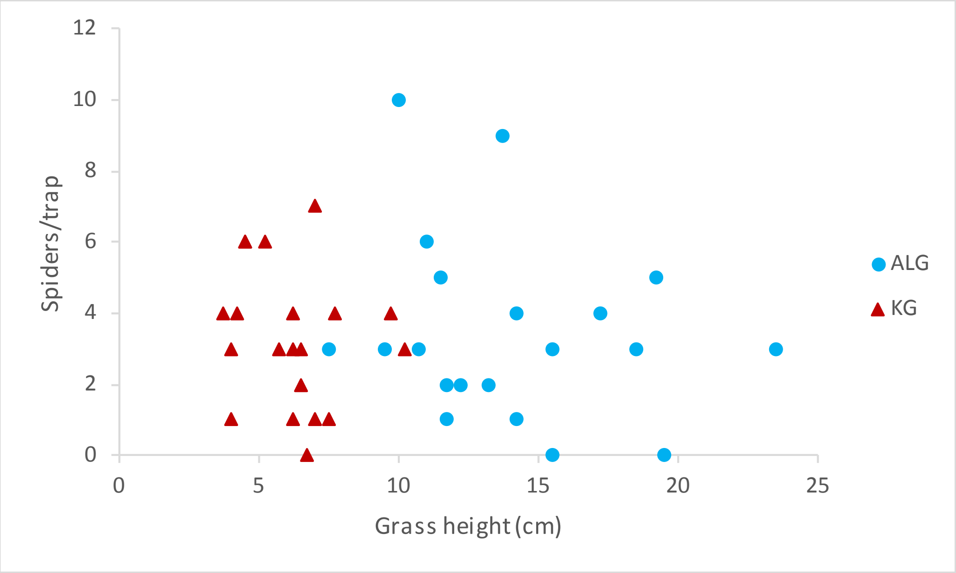


Figure 5. Number of crickets (A) and spiders (B) per trap plotted against average grass height in African lovegrass (*E. curvula*) and kangaroo grass (*T. triandra*) (points) with model predictions (lines) where the model was significant.

Table 9. Cricket and spider abundance predicted from grass height and type hierarchical generalised linear mixed model results showing trends (slope) and standard error.

Significance is indicated by the Wald statistic (X^2) and p values as follows: *p<0.05, **p<0.01, ***p<0.001. ALG: African lovegrass, KG: kangaroo grass.

Variable	Term	D.f.	X^2	Slope	Standard error
Cricket	Grass height . ALG			-0.1523	0.0405
	Grass height . KG			-0.1239	0.0757
	Grass height .dominant grass	2	20.99***		
Spider	Grass height . ALG			-0.0342	0.0297
	Grass height . KG			-0.0801	0.0688
	Grass height . dominant grass	2	1.434		

4.2.3 Temperature

The mean number of hours per day ground temperature exceeded lizard critical maximum body temperature (40 °C) was significantly greater (p=0.008) in kangaroo grass than African lovegrass (Table 11 and Figure 7).

Table 10. Mean hours per day ground temperature exceeded maximum critical body temperature (40 °C) in African lovegrass (*E. curvula*) and kangaroo grass (*T. triandra*) at the release site.

Variable		Mean	Standard deviation	N
Hours per day over 40 °C	African lovegrass	1.02	1.902	6
	Kangaroo grass	3.34	1.701	8

	Statistic test	Wald statistic=6.968, p=0.008

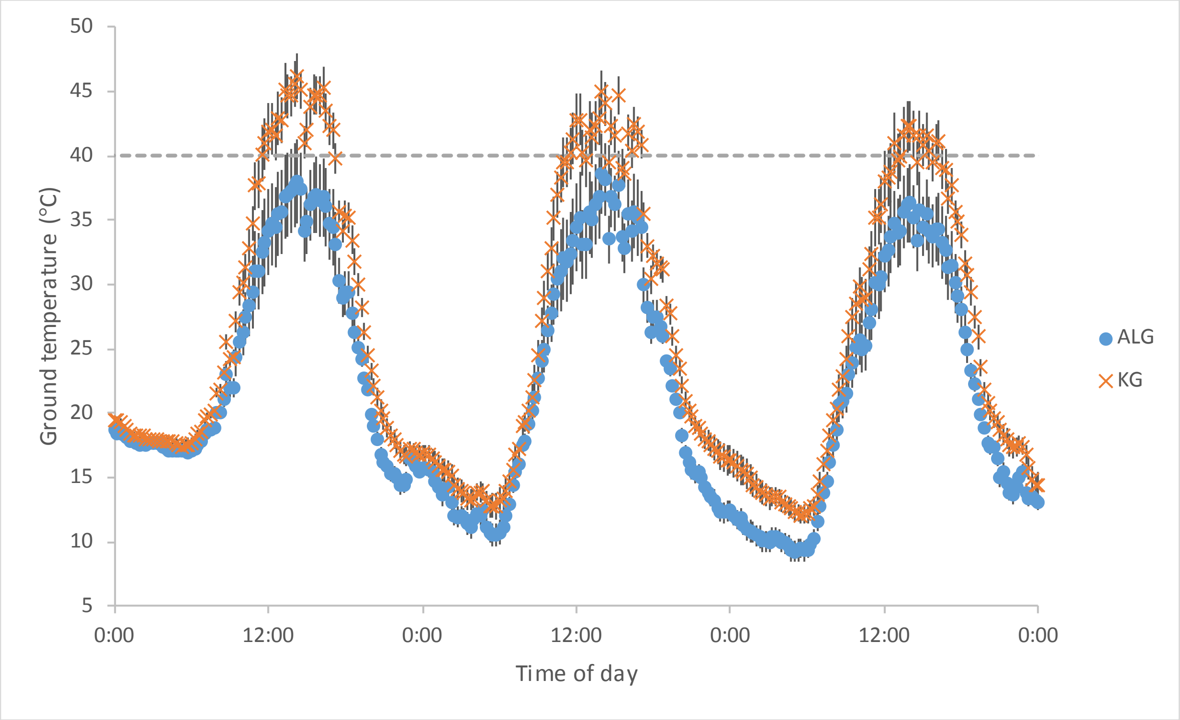


Figure 6. Mean ground temperatures throughout the day (±SE) in African lovegrass (N=6) and kangaroo grass (N=8).

The three days shown are representative of days recorded. The horizontal dashed line indicates the critical maximum body temperature of a sympatric species, *Suta flagellum* (40 °C) recorded by Spellerberg (1972). ALG: African lovegrass, KG: kangaroo grass.

4.3 Lizard habitat preference

I aimed to determine occupancy rates of *D. impar* released into enclosures of mixed African lovegrass and kangaroo grass to determine habitat preferences.

D. impar was detected at 45 (27%) of the 164 tiles available in enclosures.

Table 11. Number and percentage of tiles recording *D. impar* captures.

Number of captures	Number of tiles recording captures	Percentage (%)
0	119	72.6
1	29	17.7
2	10	6.1
3	5	3.0
4	1	0.6
5	0	0
1 or more	45	27.4
Total	164	100

Table 12. Description and summary of explanatory variables from enclosures at the release site (Scottsdale).

Variable	Description	Range (mean)		N
Grass height (cm)	Average height calculated from four measures in 1 m^2 quadrat	African lovegrass	3.5-23 (13.78)	50
		Kangaroo grass	2.5-13.5 (6.83)	81
		Mixed	5.25-16.25 (11.03)	33
Grass structural complexity	Measure of complexity Complexity=Ln(mean height*variance in height)	African lovegrass	2.35-8.14 (5.66)	50
		Kangaroo grass	-0.18-5.40 (2.98)	81
		Mixed	0.77-7.35 (4.95)	33
Biomass	Visual estimation of above ground biomass	Very low		25
		Low		53
		Medium		63
		High		23
Dominant grass	Dominant species in 1 m^2 quadrat	African lovegrass		50
		Kangaroo grass		81
		Mixed pasture		33
Ground cover	Visual estimation of ground cover into five categories	40-60%		19
		60-80%		13
		80-100%		141
Rock cover	Visual estimation of rock cover into five categories	0		137
		<5%		7
		5-20%		19
		20-40%		1

4.3.1 Modelling occupancy

The hierarchical generalised linear mixed model showed *Delma impar* occupancy was related to grass structural complexity surrounding the tile (Table 14). *D. impar* had a higher probability of occurring under tiles surrounded by complex grass structure (p=0.047) when modelled with presence/absence data. Grass structural complexity had a greater effect on *D. impar* occupancy in kangaroo grass than African lovegrass (Figure 7). At low grass complexities, *D. impar* occupancy in African lovegrass was greater but at high grass complexities, occupancy in kangaroo grass was greater (Figure 7).

The final *D. impar* occupancy model contained only grass complexity as other habitat variables (height, ground cover and rocks) were correlated with complexity and did not improve the model when they were included. The interaction of complexity and grass type on its own returned the best model fit.

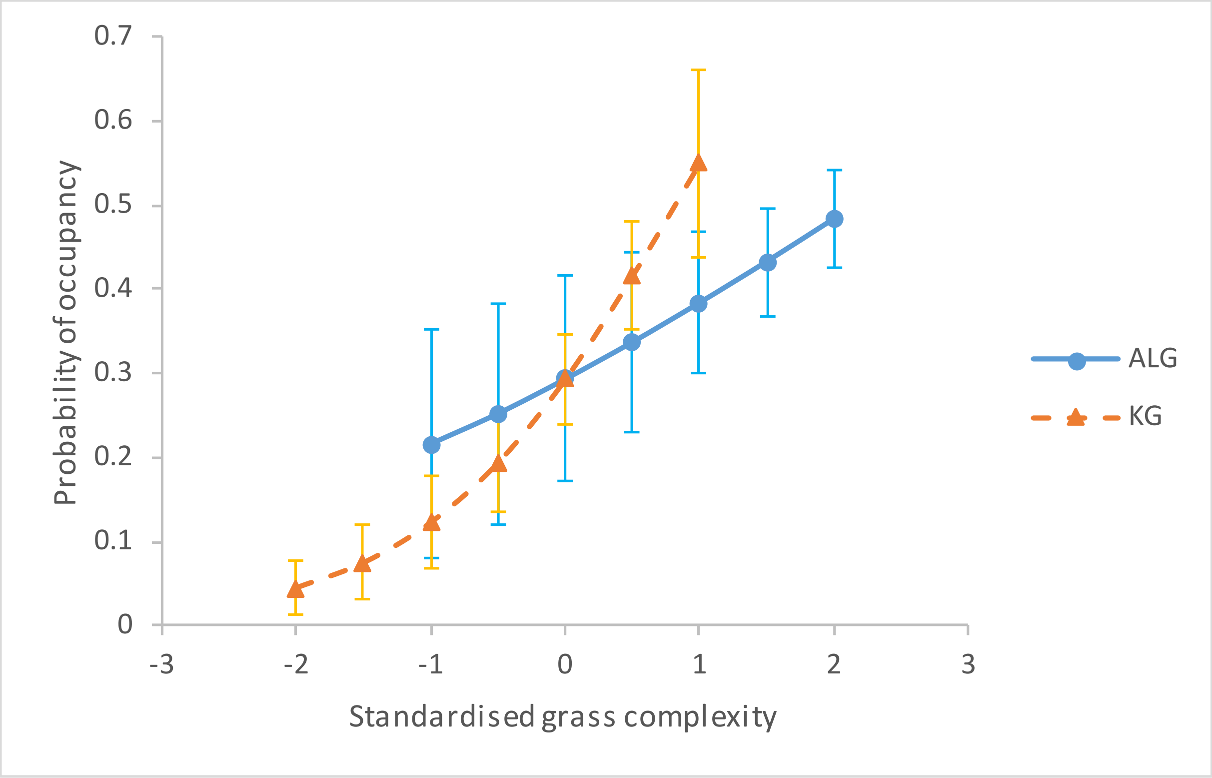


Figure 7. Predicted *D. impar* occupancy and standardised grass complexity modelled with presence/absence data.
Probability of occupancy refers to probability over all ten checks.

Table 13. *D. impar* occupancy hierarchical generalised linear mixed model results showing trends (slope) and standard error.

Significance is indicated by the Wald statistic (X^2) and p values as follows: *p<0.05, **p<0.01, ***p<0.001.

Variable	Term	D.f.	X^2	Slope	SE
Grass complexity	Standard grass complexity . ALG			0.408	0.404
	Standard grass complexity . KG			1.083	0.530

	Standard grass complexity . dominant grass	2	6.129*		

4.3.2 Microhabitat use

Occupancy rate was greater under tiles in African lovegrass than kangaroo grass and mixed grass (Chi square test, p=0.054, Table 14). Forty percent of tiles in African lovegrass, 21% of tiles in kangaroo grass and 24% in mixed grass type recorded one or more *D. impar* detections (Table 15) despite lizards having an approximately equal opportunity to occupy each grass type. Twenty percent of tiles lizards were released at recorded a *D. impar* presence compared to 28.4% of non-release tiles. There is therefore no evidence lizards used release tiles more than others.

D. impar detection rate was independent of groundcover (p=0.108,) and rock cover (p=0.73) around the tile (Table 15 and Table 16).

Table 14. Number and percentage of tiles in African lovegrass, kangaroo grass and mixed grass, and number and percentage of tiles recording one or more captures.

Grass type	Number of tiles	Percentage of tiles in category (%)	Number of tiles recording one or more detections	Percentage of tiles recording one or more detections (%)
African lovegrass	50	30	20	40
Kangaroo grass	81	49	17	21
Mixed grass	33	20	8	24
Statistic result	X^2=5.82 , p=0.0054			

Table 15. Percentage of tiles recording zero, one, two, three and four captures in each ground cover class.

Note: There were no tiles at the release site with surrounding groundcover of classes 1 (<20%) or 2 (20-40%).

Ground cover class	Percentage of tiles with *Delma impar* captures (%)					Percentage of tiles recording any number of captures (%)	Total number of tiles
	Number of captures						
	0	1	2	3	4		
3: 40-60%	89	11	0	0	0	11	19
4: 60-80%	57	29	14	0	0	43	14
5: 80-100%	72	18	6	4	1	28	131
Statistic result	X^2=4.44 , p=0.108						

Table 16. Percentage of tiles recording captures in each rock cover class.

Rock cover	Percentage of tiles recording any number of captures (%)	Total number of tiles
None	29	137
<5%	14	7
5-20%	16	19
20-40%	100	1
Any amount of rock	18	27
Statistic result	$X^2=4.76$, $p=0.19$	

4.4 Explanations for lizard habitat preference

To determine the reasons for increased *D. impar* occupancy in high grass complexity areas, I investigated how invertebrate abundance and duration of time ground temperatures exceeded lizard critical maximum body temperature were affected by grass complexity.

4.4.1 Invertebrates

Cricket abundance per trap significantly decreased with increasing grass complexity surrounding the trap ($p<0.001$, Figure 8 and Table 18). Average cricket abundance per trap was higher overall in kangaroo grass than African lovegrass ($p<0.001$, Table 8). Spider abundance per trap was unrelated ($p=0.976$) to grass complexity surrounding the trap in either grass species (Figure 8 and Table 18).

A)

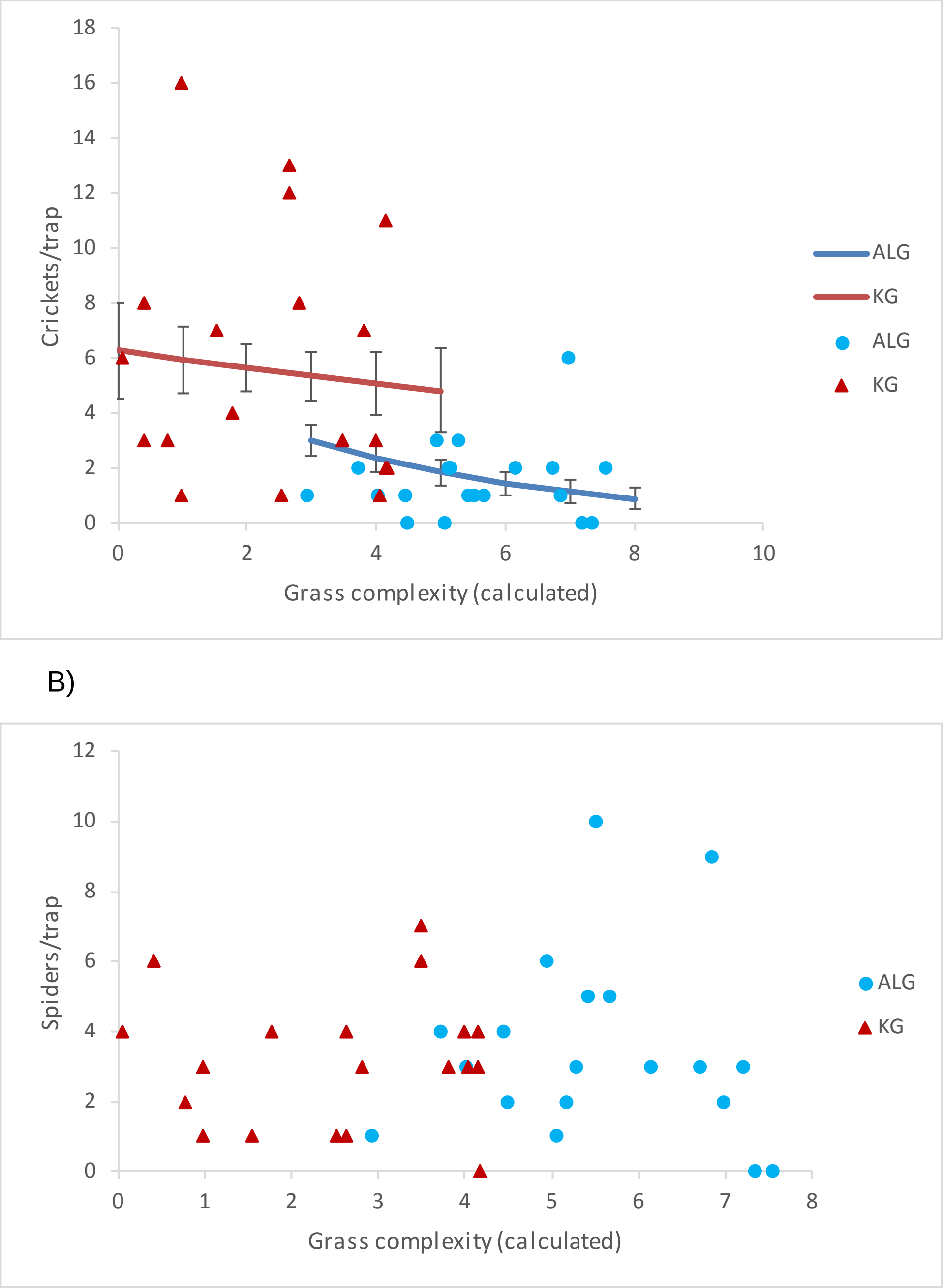


Figure 8. Number of crickets (A) and spiders (B) per trap plotted against grass complexity in African lovegrass (*E. curvula*) and kangaroo grass (*T. triandra*) (points) with model predictions (lines) where the model was significant.

Table 17. Cricket and spider abundance predicted from grass complexity and type hierarchical generalised linear mixed model results showing trends (slope) and standard error.

Significance is indicated by the Wald statistic (X^2) and p values as follows: *p<0.05, **p<0.01, ***p<0.001.

Variable	Term	D.f.	X^2	Slope	Standard error
Cricket	Grass complexity . ALG			-	0.0719

				0.2432	
	Grass complexity . KG			-0.0519	0.1021
	Grass complexity . dominant grass	2	15.04***		
Spider	Grass complexity . ALG			0.0031	0.0564
	Grass complexity . KG			-0.0109	0.1054
	Grass complexity . dominant rass	2	0.976		

4.4.2 Temperature

Number of hours per day ground temperature exceeded lizard critical maximum body temperature (40 °C) decreased with increasing near grass height above the logger (p=0.005, Figure 9 and Table 19). The average number of hours per day ground temperature exceeded critical maximum temperature was lower in African lovegrass than kangaroo grass (p=0.008, Table 10 in section 4.2.3) The African lovegrass provided a cooler environment.

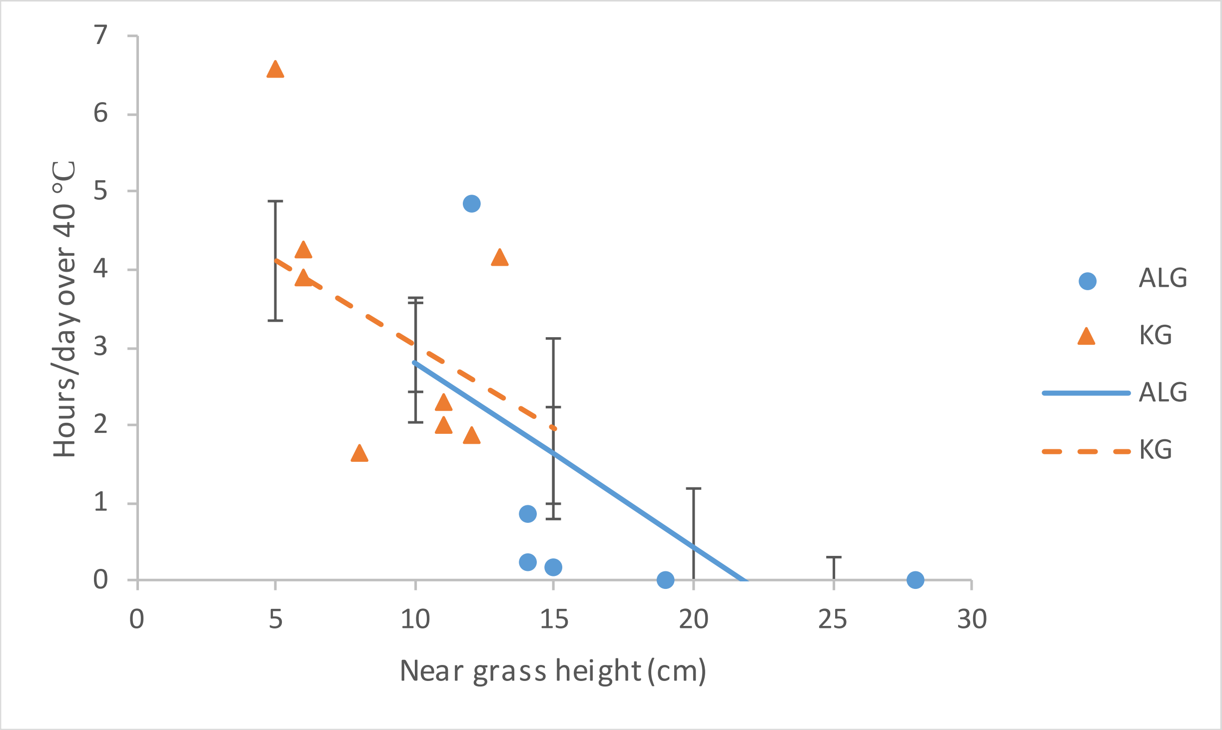


Figure 9. Hours per day temperature exceeded lizard critical maximum body temperature (40 °C) against near grass height in African lovegrass (ALG, *E. curvula*) and kangaroo grass (KG, *T. triandra*) (points) with model predictions (lines) where the model was significant.

Table 18. Results of hierarchical generalised linear mixed model showing trends (slope) and standard error.

Significance is indicated by the Wald statistic (X^2) and p values as follows: $*p<0.05$, $**p<0.01$, $***p<0.001$.

Variable	Term	D.f.	X^2	Slope	Standard error
Hours >40 °C	Near grass height . ALG			-0.2373	0.0846
	Near grass height . KG			-0.215	0.155
	Near grass height . dominant grass	2	10.64**		

4.5 Initial persistence at the release site

Delma impar was detected 68 times over 10 survey days. The longest time between release and recapture of individuals was 65 days (3 individuals). Thirty-one (46%) animals were identified, with 21 of the translocated individuals being recaptured. Eight individuals were caught and identified multiple times. Lizards could not be identified in 37 (54%) of the detections. Therefore, at least 43% (21) of the 49 released lizards were recaptured and identified between 9 days and 65 days (9 ½ weeks) after release.

4.6 Summary

In summary, the source and release sites were fairly similar *Delma impar* environments. The release site had similar vegetation structure, invertebrate prey food availability and lower frequency of occurrence of high ground temperature compared to the source site. Within the release site, African lovegrass was superior in terms of providing a cooler environment, high grass height, high grass complexity but had lower potential food availability. Kangaroo grass had frequent high ground temperature, low grass height, low grass complexity but had high potential food availability. *D. impar* occupancy increased with increasing grass complexity in both African lovegrass and kangaroo grass. *D. impar* occupancy increased more rapidly in kangaroo grass as grass complexity increased. Potential food availability decreased with increasing grass height and complexity. Frequency of high ground temperatures decreased with increasing grass height. Importantly, there was strong evidence of high survival rates of *D. impar* for the first two months post release.

Chapter 5: Discussion

5.1 *Sites comparison*

Similarity in habitat (and associated resources and conditions) between source and release sites is likely to increase reintroduction success (Roe *et al.*, 2010). Therefore, biophysical factors at the release site were compared to the source site to determine if the release site contained habitat features likely to be required by *D. impar*.

As predicted by hypothesis one, the two sites had broadly similar habitat features for *D. impar*. The vegetation structure appeared to be generally suitable at the release site and there was a lower frequency of occurrence of ground temperature exceeding lizard critical maximum body temperature at the release site. Cricket and spider abundance were similar between the sites suggesting food availability is likely to be suitable. At the release site, there were patches of lower ground cover which may result in areas of the release site where vegetation is too sparse (suboptimal) for *D. impar* (Robertson and Smith, 2010; Howland *et al.*, 2014; Howland *et al.*, 2016; Brown *et al.*, 2011), though the majority of the site had high groundcover (>80%) and similar to the source site. The shorter duration of time at the release site with temperatures exceeding critical body temperature suggests a larger proportion of each day will be usable by *D. impar* for activity (for example, foraging) before needing to retreat to thermal refugia. There was much more African lovegrass and kangaroo grass at the release site. The implication of this differences are discussed below. In short, it appears the chosen area of Scottsdale Reserve has the potential to be a suitable release site for *D. impar*.

5.1.1 Temperature

The frequently observed occurrence of ground temperature above lizard critical maximum body temperature at the source site (Table 5) suggests *D. impar* survives environmental temperatures above its physiological maximum which is assumed to be 40 °C based on evidence from the little whip snake (*Suta flagellum*) which occurs in similar grassy habitat (Spellerberg, 1972). This is likely due to the presence of thermal refugia, either dense grass or litter that provides shade, and/or invertebrate soil burrows and soil cracks. This finding suggests that if thermal refugia are present at Scottsdale (in any form), *D. impar* will persist when ground temperature exceeds physiological maxima.

Candy (2008), in work in South-West Victoria, found the combined clay content of the A and B soil horizons was the single best predictor of *D. impar* presence out of nine biophysical variables tested using regression modelling. The EPIC site is in flat topography and soil is likely to be loamy, perhaps favouring the likelihood of invertebrate burrows and soil cracks forming. Release enclosures were in sloping topography and flat midslope positions. As a result, soil is likely to be stony and unlikely to contain high quantities of clay and organic matter perhaps decreasing the likelihood of invertebrate burrows and soil cracks forming. Occasional rocks, which do not occur at the source site, may provide thermal refugia as *D. impar* has been recorded under rocks at another site on the Monaro Tablelands approximately 45 km away (Dorrough). However, as discussed in the next section, the most likely thermal refugia at the release site is tall and dense grass, particularly African lovegrass under which the thermal maxima of 40 °C was rarely recorded during the observation period (Figure 6).

The shorter duration of time with temperature exceeding critical body temperature at Scottsdale (despite similar grass height) may partially be due to cooler weather conditions due to higher altitude and proximity to mountain ranges (altitude 690m compared to 590m at EPIC (Geoscience Australia)).

5.2 Release site grass comparison

The habitat suitability of African lovegrass is not known and it is assumed *D. impar* occupied kangaroo grass when it occurred at Scottsdale in the past. Thus, a key question was, can African lovegrass and kangaroo grass at Scottsdale provide suitable habitat in terms of vegetation structure, invertebrate prey availability and thermal conditions?

High structural complexity native and exotic grass is considered high quality habitat for *D. impar* (Howland *et al.*, 2016). Therefore, the lower average grass complexity in kangaroo grass compared to African lovegrass (3.0 ± 1.4 vs. 5.7 ± 1.3) may suggest reduced habitat quality in kangaroo grass at its current complexity. The high ground cover in each grass species matches *D. impar* habitat requirements (O'Shea, 2005).

Crickets and spiders are important prey items for *D. impar* (Nunan, 1995{Kutt, 1998 #61)}. These prey were present in both African lovegrass and kangaroo grass, but there was a significantly lower cricket abundance in African lovegrass (Table 8). This suggests African lovegrass may provide lower quality foraging habitat than kangaroo grass. Therefore monocultures of African lovegrass may not be suitable habitat for *D. impar*. The abundance of crickets and spiders showed either no relationship or a declining relationship with increasing grass complexity (Figure 8). Thus, it appears that short to medium complexity grass contains the highest quality *D. impar* foraging habitat

The frequent occurrence of ground temperature in kangaroo grass exceeding critical maximum lizard body temperature (40 °C) suggests that without some form of high temperature thermal refugia, the relatively short kangaroo grass at the release site may provide suboptimal *D. impar* summer habitat. This could be due to either having inadequate refugia from high temperatures or having too few hours each day within the preferred temperature range allowing adequate feeding activity. This may drive the avoidance of kangaroo grass by *D. impar*. At the release site, kangaroo grass was typically short and of low biomass. Shelter under grass litter is unlikely to provide substantial thermal refugia. The presence of soil thermal refugia is thought to be low at Scottsdale however occasional surface rocks may serve a similar function (discussed above). Short grass may also result in high predation risk (Sato *et al.*, 2014). The potential for long term persistence of *D. impar* in kangaroo grass at its current height is therefore uncertain and the population will need to be further monitored to determine if *D. impar* persist solely in short kangaroo grass in the long term.

However, African lovegrass is likely to have provided thermal refugia for *D. impar* as it was rare for ground temperature under African lovegrass to exceed the critical maximum body temperature (Table 10/Figure 6). The lower maximum temperature under African lovegrass is likely due to its greater height (Table 6). *D. impar* is likely to have longer periods available for activity in African lovegrass due to rarely needing to retreat to thermal refugia. The kangaroo grass at the release site may be a better foraging habitat, but patches of African lovegrass may provide superior thermoregulatory habitat.

However, African lovegrass may be too dense and tall. Dense invasive grasses can render the thermal characteristics of an area suboptimal for lizards (Hacking *et al.*, 2014). The rainbow skink (*Carlia schmeltzii*), a heliothermic reptile from Australian tropical savannah, avoided sites invaded by a dense invasive grass due to low temperature and altered habitat structural heterogeneity. The weed grew into a dense lawn preventing ambient temperatures reaching temperatures warm enough for lizard activity (Hacking *et al.*, 2014). *D. impar* in African lovegrass may display similar behaviours in spring and autumn when lizard requirements for heat may be greater than in summer, the time of year this study was conducted in, due to the high density and thick growth habit of African lovegrass. Too little sunlight may penetrate areas of dense African lovegrass growth resulting in areas possibly not satisfying *D. impar* thermal requirements in spring or autumn. However, thigmothermic species tolerate cooler conditions (Bury and Balgooyen, 1976) than heliotherms and *D. impar* brumate during winter, likely an adaption to their cold grassland habitat (ref). *D. impar* may tolerate the cool microhabitat in African lovegrass, particularly if they have access to the shorter more open kangaroo grass available within release enclosures.

Kangaroo grass in release enclosures contained important *D. impar* food families, was relatively short and low in biomass and frequently exceeded critical maximum body temperature. African lovegrass contained an equal abundance of spiders but fewer crickets, was tall and high in biomass and very rarely exceeded critical maximum body temperature. African lovegrass appears to provide critical summer thermal refugia, particularly if soil refugia are rare. However, African lovegrass may be suboptimal spring habitat due to its high density and tall height causing sub-optimally low temperature. Areas with mixtures of the shorter more open kangaroo grass with the taller denser African lovegrass may be the most suitable habitat at the Scottsdale Reserve.

5.3 Delma habitat use/preference

The key research question was, what factors drive the use of microhabitats at the release site? The short answer is grass complexity, heterogeneity and thermal conditions.

5.3.1 Veg

Grass complexity

D. impar tile occupancy responded to grass complexity surrounding the tile. As grass complexity increased in both African lovegrass and kangaroo grass, the probability of occupancy increased dramatically (Figure 7). High complexity grass, maximal in grass both tall and of variable height, had the highest predicted *D. impar* occupancy. Short and low complexity grass was occupied at a low rate. Possible reasons are explained in the next three sections. This study confirms the requirement of tall and heterogeneous grass as *D. impar* habitat (Howland *et al.*, 2016; Dorrough and Ash, 1999).

Unfortunately, there was little tall kangaroo grass or short African lovegrass at the release site. Therefore, a comparison of *D. impar* occupancy of both grasses at the same grass complexity values could be achieved for a narrower range of grass complexities (Figure 7).

Grass species comparison

At low grass complexities, African lovegrass was occupied at a higher rate and at high grass complexities kangaroo grass was occupied at a higher rate. Thus the effect of grass complexity on *D. impar* habitat occupancy was more important in kangaroo grass than native grass (Figure 7) matching the findings in Howland *et al.* (2016).

This study provides no evidence of avoidance of the exotic African lovegrass by *D. impar*. This study provides evidence of *D. impar* occupying the exotic African lovegrass at predicted equal or greater rates than the native kangaroo grass. At least in the short term, African lovegrass provided some sort of occupiable habitat for *D. impar*. My research supports previous findings that vegetation structure is critical for *D. impar* habitat and that grass species has a lesser importance (Howland *et al.*, 2016; Dorrough and Ash, 1999). *D. impar* has been recorded occurring and reproducing in multiple exotic grasses: serrated tussock, Chilean needle grass, Phalaris, Yorkshire Fog (Howland *et al.*, 2016; Dorrough and Ash, 1999; O'Shea, 2005; Thompson, 2006) and some areas of the source site where *D. impar* occurred were dominated by exotic grasses. This finding concurs with and extends previous research that floristically degraded grasslands can provide habitat for *D. impar* (Howland *et al.*, 2016). Grasslands invaded by African lovegrass may provide habitat. This is a valuable finding due to the possibility of African lovegrass invading grassland reserves in the ACT containing *D. impar*. The possibility of *D. impar* inhabiting floristically degraded grasslands should be considered in reserve management decisions.

The jacky lizard (*Amphibolurus muricatus*), another reptile native to South-Eastern Australia has been recorded occupying African lovegrass for substantial proportions of the day (Hitchen *et al.*, 2011) suggesting this grass may provide habitat to a wider range of reptiles.

The finding that *D. impar* occupied African lovegrass and kangaroo grass equally when given a choice of grass types and findings that *D. impar* occur in exotic vegetation (Dorrough and Ash, 1999) contrasts with Martin and Murray (2011) prediction that *D. impar* is threatened by exotic plant invasions. They developed a predictive framework based on exotic plant and native animal species traits to predict the threat caused by exotic plant invasion. *D. impar* is predicted to be threatened due to matching the criteria of small body size, small home range, habitat specialist, insectivorous, part dietary specialist and oviparity (egg laying). African lovegrass is predicted to be harmful due to matching the criteria of novel growth form and large spatial coverage (Martin and Murray, 2011). Occupancy in this study and previous research showing *D. impar* occurs in exotic dominated grassland does not support the prediction.

However, long term occupancy data is needed to conclusively determine habitat suitability of African lovegrass as two months of occupancy after release may be too short for lizards to either choose to move to higher quality habitat or show symptoms of suboptimal habitat (emaciation from lack of food or from short activity period due to lack of heat).

Structural heterogeneity is important for *D. impar* (Howland *et al.*, 2016) and reptiles generally (Martin and Murray, 2011) due to providing varied microhabitats for thermoregulation (Hacking *et al.*, 2014), predator avoidance (Sato *et al.*, 2014) and prey availability (Bateman and Ostoja, 2012) with negative effects on growth and physiology recorded of lizards living in dense exotic vegetation (Downes and Hoefer, 2007). African lovegrass monocultures can be homogenous and may provide suboptimal *D. impar* habitat possibly due to not providing the diversity of microhabitats necessary.

5.3.2 Invertebrates

The higher *D. impar* occupancy in high structural complexity grass was not explained by greater food availability in either grass species. This was contrary to hypothesis three that high grass complexity would result in greater invertebrate prey. As discussed above, the abundance of crickets and spiders showed either no relationship or a declining relationship with increasing grass complexity. This may have been expected to cause lower *D. impar* occupancy in high complexity grass. However, *D. impar* occupancy in both grasses increased with increasing grass complexity.

The lower abundance of crickets and similar abundance of spiders in African lovegrass than kangaroo grass would similarly be expected to reduce *D. impar* occupancy however occupancy was similar over the range of grass complexities in African lovegrass and kangaroo grass (Figure 7). Due to the mixture of grass species and grass structure, *D. impar* may have been able to use different parts of enclosures for different purposes. Kangaroo grass may have been used as foraging habitat and African lovegrass for shelter and high temperature refugia. An alternative explanation is that the lower cricket abundance in African lovegrass was adequate in the short term and didn’t affect *D. impar* behaviour.

Hacking *et al.* (2014) similarly found food availability in an exotic grass was not the reason driving lower rainbow skink (*Carlia schmeltzii*) occupancy in exotic grass. Lizards were likely avoiding the exotic grass due too cool thermal conditions.

5.3.3 Temperature

Kangaroo grass in release enclosures was mostly short and had temperatures frequently exceeding critical maximum body temperature (40 °C, Table 10 and Figure 6). Ground temperature exceeded critical maximum temperature in complex grass, mostly African lovegrass, relatively rarely. Thus the thermal conditions recorded in complex grass may be driving the predicted greater *D. impar* occupancy in high complexity grass of both species. This mechanism of avoidance of short grass partly due to environmental temperatures exceeding critical maximum body temperatures has been described in two alpine skinks (Sato *et al.*, 2014).

African lovegrass appears to provide a cooler environment than kangaroo grass at any given grass height (Figure 9) and was taller than kangaroo grass. Thus the thermal conditions recorded in African lovegrass may be driving the higher *D. impar* occupancy rate in African lovegrass compared to kangaroo grass (40% vs 21%). Temperature frequently exceeded critical maximum temperature at all temperature loggers placed in kangaroo grass, showing temperature conditions were similar across kangaroo grass areas.

5.4 Delma initial persistence

The key research question was, do *D. impar* persist in the short term following translocation into a mix of native and exotic grass?

At least 43% of individuals released were recaptured and identified at some time in the two months following release with three individuals recaptured 65 days after release. These results imply a high translocation survival rate and initial persistence possibly indicating suitability of the release site, at least in the short term. The released population will need to be monitored to determine long term translocation success.

Previous *D. impar* translocations have not published such short term persistence data and long term persistence results from previous trial translocations are poorly known (Robertson and Smith, 2010). Therefore, it is not known whether 43% of released individuals recaptured in 2 months in this study is high. Seventy-five percent and 67% of 12 *D. impar* individuals released into enclosures at two sites were recaptured during one year of monitoring using tiles and pitfall traps in a translocation in Victoria (Parks Victoria, 2002). A translocation aiming to release 900 *D. impar* individuals (75 per site at 12 sites) in Victoria over at least 10 years began in 2013 (O'Shea, 2013). Initial results have not been published.

The success of a translocation of a reptile with similar functional attributes (USA semi fossorial sand skink, *Plestiodon reynoldsi*) was attributed to habitat heterogeneity found in release enclosures (McCoy *et al.*, 2014). However, translocated individuals of another reptile with similar functional attributes (UK semi fossorial slow worm, *Anguis fragilis*) had declining body condition, population size and no evidence of reproduction in part due to poor release site habitat quality (Platenberg and Griffiths, 1999). The success of a lizard translocation (St Croix ground lizard, *Ameiva polops*) was attributed to the eradication of predators, life history of the species (short time to maturity), large animal size, condition of habitat, soft release, use of adults, interagency collaboration and systematic assessment (Fitzgerald *et al.*, 2015 143).

It can take a long time to determine translocation success, judged by the establishment of self sustaining populations where individuals born locally produce offspring, especially in long lived species (Towns and Ferreira, 2001) as is the case for *D. impar*. Towns and Ferreira (2001) estimated it may take more than 20 years to judge the success of a translocation of three skink species in New Zealand.

In summary, the literature on *D. impar* and on other reptiles provides some hopeful examples that ground dwelling, fossorial reptiles can be translocated successfully adding weight to the short term persistence data from this translocation. Bush Heritage Australia, the managers of the release site, are committed to monitoring the release site for the next three years.

Long term persistence - Climate change

Climate change may lead to higher ambient temperatures that will lead to higher ground temperatures and shorter time for reptiles to forage within their operating temperature range (Huey *et al.*, 2010). Sinervo *et al.* (2010) describe this effect causing worldwide extinctions of lizards due to energetic shortfalls in spring, when energy demands for reproduction are greatest, due to lizards retreating to thermal refugia earlier. Thus, cool thermal environments may be increasingly important to prevent or slow the shortening duration of activity periods of lizards as a result of climate change. In the case of *D. impar* in grasslands and at our release site, the availability of tall dense grass may be increasingly important as air temperatures rise due to climate change.

5.5 Applying translocation principles

This translocation was conducted following the guidelines presented in literature reviews (Fischer and Lindenmayer, 2000; Germano and Bishop, 2009; Sheean *et al.*, 2012). To increase the likelihood of success, guidelines suggest having a large number of founder individuals (>100), translocating wild not captive bred animals, minimising time in captivity, using appropriate soft release tactics, translocating breeding adults, ensuring initial causes of decline are removed, high release site habitat quality, explicit measures of success are identified prior to translocation, experimental framework used to test particular hypotheses and there is a commitment to post release monitoring.

My study, in collaboration with ACT government conservation managers and Bush Heritage Australia applied guidelines as follows:

- A large number (more than 100) wild individuals were released
- Animals were kept in captivity for a few hours
- Half the individuals were released into enclosures. The other half of individuals released into open grassland were not part of my research.
- Most were adults of both sexes and some appeared to be gravid.
- Bush Heritage Australia has removed threatened processes at the release site, particularly grazing pressure and complete cessation of cultivation.
- Use of an experimental framework to test clear hypotheses
- Explicit measures of success identified prior to translocation
- And Bush Heritage Australia is committed to long term monitoring of the released population.

Even if the translocation fails in the long term, this research has provided considerable insights into *D. impar* habitat preference and the factors driving habitat use.

5.6 Implications

5.6.1 Management

Grassland reserves

This study confirms that *D. impar* are dependent on tall complex grass structure. Short grass provides poor habitat and is rarely occupied. Land management where *D. impar* occurs, must maintain tall structurally complex grass for *D. impar* persistence. Grass must be structurally complex, whether the grass vegetation is native or exotic, to provide *D. impar* habitat. This study has shown *D. impar* occupy both African lovegrass and kangaroo grass for two months following translocation when in enclosures containing a mix of the grasses. Further monitoring is required to determine if African lovegrass will provide suitable habitat in the long term, however this finding suggests *D. impar* may be somewhat tolerant of African lovegrass invasion of their grassland habitat, concurring with previous research showing *D. impar* occur and reproduce in grasslands dominated by multiple exotic grasses (Robertson and Smith, 2010).

Scottsdale grassland management

Reducing African lovegrass height at Scottsdale by heterogenous slashing, therefore increasing grass complexity, may increase *D. impar* abundance (Figure 7) and cause a small but significant increase in cricket abundance (Figure 8). The low cricket abundance in African lovegrass may limit the *D. impar* population in the long term. Spider abundance is likely to be unaffected by a reduction in grass height. Reducing African lovegrass height to 15 cm (the current average being 13.8 cm) and even lower is unlikely to affect the ability for African lovegrass to provide thermal refugia during hot conditions (Figure 9). It is hypothesised slashing African lovegrass may improve its habitat value during cooler times of the year due to its dense growth form. Shorter grass may allow more sunlight to penetrate and heat the ground surface to a higher temperature. The spring period may be important for *D. impar* breeding and increased heat at this time of year may improve habitat quality.

Increasing kangaroo grass height at Scottsdale, possibly through managing grazing pressure especially during droughts, is likely to improve *D. impar* habitat quality. Short kangaroo grass provides poor *D. impar* habitat. Grass height should be monitored and the area managed appropriately (for example with kangaroo culling or exclusion) if grass height becomes too short. Kangaroo grass should not be slashed despite the predicted increase in cricket abundance due to exposure to high temperature.

Current management of African lovegrass at Scottsdale involves control with herbicides. This method will be detrimental to *D. impar* if surrounding kangaroo grass is short, which may occur during drought. African lovegrass can be controlled without harming *D. impar* if surrounding kangaroo grass is of adequate height and structural complexity. Kangaroo grass can be overgrazed by kangaroos (no livestock occur at Scottsdale Reserve). As African lovegrass is unpalatable to livestock and kangaroos (Firn, 2009), though undesired due its invasiveness, it is likely to be taller during drought and providing critical habitat to *D. impar*.

5.6.2 Translocation theory and practice

Results from this study contribute to a better understanding of the methods and use of translocation for reptiles. Translocation tactics used were simple (no other soft release tactics aside from fenced enclosures) but time consuming implying translocation for *D. impar* can be conducted relatively easily. Translocated *D. impar* had high short term persistence providing hope the translocation may be successful in the long term. Reintroduction to unoccupied patches of high quality habitat may be a feasible and effective conservation action for *D. impar*.

Future translocations should ensure release sites contain tall structurally complex grass and have a means of giving *D. impar* choice of habitat. Short grass may provide suboptimal summer habitat due to high ground temperatures. If future releases occur at Scottsdale, the ecotone of African lovegrass and kangaroo grass (tall and short grass) may be the best release site due to the close coexistence of high prey availability, shelter from high temperature extremes and mix of short and tall grass that may be necessary for winter and summer habitat. Detailed criteria for selecting release sites for Victorian *D. impar* translocations are specified in O'Shea (2013).

5.6.3 Habitat loss mitigation

The initial persistence of *D. impar* at the release site provides hope the translocation may be successful in the long term and that translocation may be a useful measure to mitigate habitat loss due to urban expansion. However, the success of this translocation is not expected to be known for at least 6 years (approximately double the length of time to maturity) and may be as much as 20 years (Towns and Ferreira, 2001). The success of translocation rests on the suitability of the release site (Germano *et al.*, 2015). For species such as *D. impar* with small home ranges and limited dispersal the site has to be suitable at a small scale (metres to tens of m^2). The type of grass community (natural temperate grassland, native pasture or exotic pasture) is not significantly related to *D. impar* occurrence (Howland *et al.*, 2016). Therefore, potential translocation release sites will need to be suitable at the microhabitat scale, not merely at the grass community scale and thorough planning is required. Mitigation translocations that release animals into habitat not assessed for its suitability serve no conservation purpose. The resources used to conduct such a translocation could be better used to improve management or monitoring of existing populations, conduct research on the biology of the species or conduct education programs on the value of grassland conservation.

In situations where habitat loss is unavoidable, well planned mitigation translocation may benefit the conservation of the species (Sullivan *et al.*, 2015), for example McCoy *et al.* (2014). Released populations grow rapidly in only very rare cases and as a result a translocated population is unlikely to replace a lost population. Therefore, translocations cannot truly offset the loss of a population (resulting in ‘no-net-loss’ of the species) but may improve the situation compared with no translocation. If governments require land developers to translocate threatened species prior to development, a way to improve outcomes may be to ensure translocation occurs only if suitable release sites are identified and thorough planning has been conducted.

5.7 Limitations

Release site suitability

The availability of soil high temperature refugia at the release site is unknown as an assessment of soil, soil cracks and soil invertebrate burrows was not conducted. Soil in enclosures at Scottsdale is unlikely to contain high amounts of clay due to the slope topographic position. The source site is likely to have clay rich soil due to its flat valley bottom topographic position. Other areas at Scottsdale, for example the Murrumbidgee River floodplain, may have clay rich soil. The floodplain currently has low grass cover but is being restored with native tussock grasses and may be a future translocation site.

Some uncertainty remains about *D. impar* food availability at the release site as the abundance of two of the four important invertebrate prey families was not assessed. Lepidoptera larvae and cockroach abundance was not assessed due to time constraints and few captures respectively. Thus the suitable abundance of crickets and spiders indicates the release site contains food availability that is at least partially suitable but the full suitability cannot be determined from this study.

Invertebrate and ground temperature studies at the source site were conducted in grids recording low *D. impar* capture. As a result, the findings may not reflect optimal *D. impar* habitat requirements as other areas had higher *D. impar* captures. This was not considered to invalidate the results as some *D. impar* were recorded in these locations indicating broadly suitable habitat conditions.

***D. impar* persistence**

Due to time constraints, mark recapture analysis was not conducted. This analysis would have provided estimates of population size on each survey day. As a result, current information on *D. impar* initial persistence is imprecise. Mark recapture analysis is planned for December 2016 when two years of recapture data will have been collected.

***D. impar* habitat use**

The mixed grass category was excluded from *D. impar* habitat use modelling due to model convergence issues (Section 3.9.2: Delma habitat use). This resulted in a lack of information on the *D. impar* occupancy of mixed African lovegrass and kangaroo grass areas, a concern due to the large areas at the release site containing mixed grass pasture type.

The temperature study investigated the occurrence of ground temperature exceeding lizard critical maximum body temperature (40 °C). The duration of time within *D. impar* preferred temperature range (24.5-27.5 °C) was not assessed. It was considered extreme heat was a more likely driver of habitat choice due to *D. impar*'s thigmothermic thermoregulatory mode and that *D. impar* is tolerant of very cold winter conditions found in lowland grasslands. Assessing the duration of time within the preferred temperature range may be more suitable in spring and autumn when the ability to obtain heat may be more critical.

5.8 Further research

This research is preliminary and needs to be strengthened by the following research priorities:

- Long term assessment of *D. impar* occupancy in African lovegrass.
- Assess the potential and effect of reducing African lovegrass height in dense monocultures as a way to increase habitat complexity to increase *D. impar* occupancy, invertebrate prey abundance and possibly improve spring thermal conditions.
- Studies on soil clay content, invertebrate soil burrows and lepidoptera larvae abundance at Scottsdale Reserve do determine its suitability as a *D. impar* population site.
- Lizards may be more susceptible to predation in short structurally simple grass (Sato, Hacking). Therefore, assessing *D. impar* predation risk in both kangaroo grass and African lovegrass would provide further information on habitat suitability.
- Translocation to replicated release sites in the former range of species. Scottsdale Reserve was only one replicate. Doomed populations provide a great chance to

replicate release sites as the number of animals available may be high, particularly in release sites that are true native grasslands rather than derived and partially exotic grasslands of Scottsdale Reserve.

Chapter 6: Conclusion

Translocation of individuals to patches of suitable unoccupied habitat may be a useful conservation action for dispersal limited species occurring in isolated populations. Where populations of threatened species are certain to be lost due to habitat destruction, salvage and translocation of individuals to suitable unoccupied habitat may mitigate some of the loss if translocation is thoroughly planned and considers the species biology, habitat requirements and threats affecting it (Germano *et al.*, 2015). *D. impar* may benefit in both these cases as it occurs in isolated populations, is a habitat specialist, dispersal limited and suffers from ongoing habitat loss.

The translocation release site (Scottsdale Reserve) broadly matched the population source site in vegetation structure and *D. impar* food availability. Summer thermal conditions were cooler at the release site. However, there were significant differences in vegetation structure, food availability and thermal conditions between African lovegrass and kangaroo grass at the release site. Areas dominated by African lovegrass contained significantly lower cricket abundance and similar spider abundance than kangaroo grass dominated areas possibly resulting in lower habitat quality. Therefore, African lovegrass monocultures may be of lower quality foraging habitat compared to kangaroo grass. However, lizard critical maximum body temperature was exceeded rarely and significantly less in African lovegrass compared to kangaroo grass areas. This would allow lizards to be active and forage for longer in African lovegrass potentially offsetting any impacts of reduced prey availability.

D. impar selected complex grass structures in both grass species, matching previous research (Howland *et al.*, 2016{Robertson, 2010 #79)}. As grass complexity increased, *D. impar* occupancy increased more rapidly in kangaroo grass than African lovegrass. *D. impar* appeared to occupy African lovegrass pastures, at least in the short two month time frame of this study concurring previous research that grass structure not grass species is the most important factor for *D. impar* habitat. This concurs with and extends previous findings that the species occurs in multiple exotic grasses if grass structure is suitable (Howland *et al.*, 2016{Robertson, 2010 #79)}.

A cooler summer thermal environment allowing greater hours of activity time and possibly a reduction in predation risk (not tested in this study) are the most likely explanation for *D. impar*'s habitat selection of high complexity grass. The increased *D. impar* occupancy in African lovegrass and in high complexity grass of both species was not due to higher food availability in either situation. The tall and dense characteristic of African lovegrass and relatively short characteristic of kangaroo grass at Scottsdale Reserve and the effect of grass height on the ground thermal conditions is likely to explain the higher *D. impar* capture rate in African lovegrass compared to kangaroo grass. Short grasses frequently had ground temperature exceeding lizard critical maximum temperature, forcing *D. impar* to either move to taller therefore cooler grass, or to retreat to cool soil refuges shortening their activity period.

At the release site, the ecotone between African lovegrass and kangaroo grass may be the highest quality *D. impar* habitat due to the combination of greater food availability in kangaroo grass but suboptimal (hot) thermal conditions and cool thermal conditions and high grass cover in African lovegrass. The unknown possibility for African lovegrass to lack enough heat in cooler times of year due its dense growth further indicates heterogenous areas with mixed short and tall grasses may provide the best year round habitat.

There was strong evidence of short term persistence at the release site during the two months after release, possibly indicating release site habitat suitability, at least in the short term. The translocation met the goal of short term individual persistence and high recapture rate of released individuals. The success of the translocation in the long term will only be known after detailed monitoring in the following years.

References

ACT Government, 1997. *Striped Legless Lizard (Delma impar): A vulnerable species. Action Plan No. 2,* Environment ACT, Canberra.

ACT Government, 2005. *A Vision Splendid of the Grassy Plains Extended: ACT Lowland Native Grassland Conservation Strategy. Action Plan No. 28*, Arts, Heritage and Environment, Canberra.

Armstrong, A. J., 2008. Translocation of black-headed dwarf chameleons Bradypodion melanocephalum in Durban, KwaZulu-Natal, South Africa, *African Journal of Herpetology,* **57**(1): 29-41. Available at: http://dx.doi.org/10.1080/21564574.2008.9635566

http://www.tandfonline.com/doi/pdf/10.1080/21564574.2008.9635566 (accessed 2015/07/29).

Armstrong, D. P. and Seddon, P. J., 2008. Directions in reintroduction biology, *Trends in Ecology & Evolution,* **23**(1): 20-25. Available at: http://www.sciencedirect.com/science/article/pii/S0169534707003345

http://ac.els-cdn.com/S0169534707003345/1-s2.0-S0169534707003345-main.pdf?_tid=f8e7eb40-5a93-11e5-a5d4-00000aacb360&acdnat=1442202908_8fe0a38b1d109099f80305275db305c5

Atlas of Living Australia, 2016. Atlas of Living Australia.

Bajomi, B., Pullin, A. S., Stewart, G. B. and Takács-Sánta, A., 2010. Bias and dispersal in the animal reintroduction literature, *Oryx,* **44**(03): 358-365. Available at: http://dx.doi.org/10.1017/S0030605310000281 (accessed 2010).

Bateman, H. L. and Ostoja, S. M., 2012. Invasive woody plants affect the composition of native lizard and small mammal communities in riparian woodlands, *Animal Conservation,* **15**(3): 294-304. Available at: https://www.scopus.com/inward/record.url?eid=2-s2.0-84862262526&partnerID=40&md5=2349219369d37712229339ba4d4885a7

http://onlinelibrary.wiley.com/store/10.1111/j.1469-1795.2011.00517.x/asset/acv517.pdf?v=1&t=inh7cowy&s=99dd5dd261755c051106e71376bd9de2fb658682

Batson, W. G., Gordon, I. J., Fletcher, D. B. and Manning, A. D., 2015. REVIEW: Translocation tactics: a framework to support the IUCN Guidelines for wildlife translocations and improve the quality of applied methods, *Journal of Applied Ecology,* **52**(6): 1598-1607. Available at: http://dx.doi.org/10.1111/1365-2664.12498

http://onlinelibrary.wiley.com/store/10.1111/1365-2664.12498/asset/jpe12498.pdf?v=1&t=ihczzg17&s=0fa91eb728eea72f1f83ec24723a3af185177b54

Bennet, R. S., 2011. *Reptiles & frogs of the Australian Capital Territory,* National Parks Association of the ACT, Woden, ACT.

Bolker, B. M., Brooks, M. E., Clark, C. J., Geange, S. W., Poulsen, J. R., Stevens, M. H. H. and White, J.-S. S., 2009. Generalized linear mixed models: a practical guide for ecology and evolution, *Trends in Ecology & Evolution*, **24**(3): 127-135. Available at: http://www.sciencedirect.com/science/article/pii/S0169534709000196

http://ac.els-cdn.com/S0169534709000196/1-s2.0-S0169534709000196-main.pdf?_tid=72c0eeee-e045-11e5-8495-00000aab0f02&acdnat=1456902638_4ca2547d943baf19ec89b4188010719f

Brown, G. W., Dorrough, J. W. and Ramsey, D. S. L., 2011. Landscape and local influences on patterns of reptile occurrence in grazed temperate woodlands of southern Australia, *Landscape and Urban Planning,* **103**(3–4): 277-288. Available at: http://www.sciencedirect.com/science/article/pii/S0169204611002477

http://ac.els-cdn.com/S0169204611002477/1-s2.0-S0169204611002477-main.pdf?_tid=049d15f8-3a7f-11e5-9875-00000aab0f02&acdnat=1438675471_cc9e26dc60b3344b1716b11312ce0ae2

Bury, R. B. and Balgooyen, T. G., 1976. Temperature Selectivity in the Legless Lizard, Anniella pulchra, *Copeia,* **1976**(1): 152-155. Available at: http://www.jstor.org/stable/1443785

Candy, G. L., 2008. 'The current distribution of the Striped Legless Lizard, *Delma impar*, in south western Victoria: predicting habitat associations at a landscape scale', Honours thesis, School of Science and Engineering, University of Ballarat, Mt Helen, Victoria.

Cogger, H. G., 2014. *Reptiles and amphibians of australia*, CSIRO Publishing, Collingwood VIC.

Coulson, G., 1990. *Conservation biology of the striped legless lizard (Delma impar): An initial investigation*, Technical report series No. 106, Arthur Rylah Institute for Environmental Research, East Melbourne.

Coulson, G., 1995. *Management directions for the striped legless lizard (Delma impar) in the Australian Capital Territory*, ACT Parks and Conservation Service, Tuggeranong ACT.

Dickinson, H. C., Fa, J. E. and Lenton, S. M., 2001. Microhabitat use by a translocated population of St Lucia whiptail lizards (Cnemidophorus vanzoi), *Animal Conservation*, **4**(2): 143-156. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-0009530369&partnerID=40&md5=18d55ce0fea9a1208bf3d0655d4b0c7b

http://onlinelibrary.wiley.com/store/10.1017/S1367943001001172/asset/S1367943001001172.pdf?v=1&t=id8exs1g&s=a531341bd4bab29b1cf777136a4f52dc1a010749

Dodd, C. K., Jr. and Seigel, R. A., 1991. Relocation, Repatriation, and Translocation of Amphibians and Reptiles: Are They Conservation Strategies That Work?, *Herpetologica*, **47**(3): 336-350. Available at: http://www.jstor.org/stable/3892626

Dorrough, J. and Ash, J. E., 1999. Using past and present habitat to predict the current distribution and abundance of a rare cryptic lizard, Delma impar (Pygopodidae), *Australian Journal of Ecology*, **24**(6): 614-624. Available at: http://dx.doi.org/10.1046/j.1442-9993.1999.00995.x

Dorrough, J., Close, R. and Williams, L., 1996. Rediscovery of the Striped Legless lizard, Delma impar (Pygopodidae) on the Monaro Plains of NSW, *HERPETOFAUNA*, **26**: 52-53.

Downes, S. and Hoefer, A. M., 2007. An experimental study of the effects of weed invasion on lizard phenotypes, *Oecologia*, **153**(3): 775-785. Available at: https://www.scopus.com/inward/record.url?eid=2-s2.0-34547820334&partnerID=40&md5=620060ccdb4bce42ec6c774fe16e12e7

http://download.springer.com/static/pdf/807/art%253A10.1007%252Fs00442-007-0775-2.pdf?originUrl=http%3A%2F%2Flink.springer.com%2Farticle%2F10.1007%2Fs00442-007-0775-2&token2=exp=1461662420~acl=%2Fstatic%2Fpdf%2F807%2Fart%25253A10.1007%25252Fs00442-007-0775-2.pdf%3ForiginUrl%3Dhttp%253A%252F%252Flink.springer.com%252Farticle%252F10.1007%252Fs00442-007-0775-2*~hmac=f26ccdd02dd9fb4047ee7169bf32ecde431c928befaa9913b337a8932b429f2c

Environment ACT, 2005. *National Recovery Plan for Natural Temperate Grassland of the Southern Tablelands (NSW and ACT): an endangered ecological community*, Environment ACT, Canberra.

Firn, J., 2009. African lovegrass in Australia: A valuable pasture species or embarrassing invader?, *Tropical Grasslands*, **43**(2): 86-97. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-77949297721&partnerID=40&md5=08488f552636442906096c30a2f270ec

Fischer, J. and Lindenmayer, D. B., 2000. An assessment of the published results of animal relocations, *Biological Conservation*, **96**(1): 1-11. Available at: http://www.sciencedirect.com/science/article/pii/S0006320700000483

Fitzgerald, L. A., Treglia, M. L., Angeli, N., Hibbitts, T. J., Leavitt, D. J., Subalusky, A. L., Lundgren, I. and Hillis-Starr, Z., 2015. Determinants of successful establishment and post-translocation dispersal of a new population of the critically endangered St. Croix ground lizard (Ameiva polops), *Restoration Ecology*, **23**(6): 776-786. Available at: http://dx.doi.org/10.1111/rec.12248

http://onlinelibrary.wiley.com/store/10.1111/rec.12248/asset/rec12248.pdf?v=1&t=ins7dmc7&s=fe9735af95655f97a0434cf7cac5589dac81a382

Geoscience Australia, Geoscience Australia, Canberra.

Germano, J. M. and Bishop, P. J., 2009. Suitability of amphibians and reptiles for translocation, *Conserv Biol,* **23**(1): 7-15. Available at: http://www.ncbi.nlm.nih.gov/pubmed/19143783

Germano, J. M., Field, K. J., Griffiths, R. A., Clulow, S., Foster, J., Harding, G. and Swaisgood, R. R., 2015. Mitigation-driven translocations: are we moving wildlife in the right direction?, *Frontiers in Ecology and the Environment,* **13**(2): 100-105. Available at: http://dx.doi.org/10.1890/140137 (accessed 2015/07/13).

Griffith, B., Scott, J. M., Carpenter, J. W. and Reed, C., 1989. Translocation as a species conservation tool: status and strategy, *Science,* **245**(4917): 477-480. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-0024928186&partnerID=40&md5=3753a1a34ba19e37b4c0b95981271d03

Hacking, J., Abom, R. and Schwarzkopf, L., 2014. Why do lizards avoid weeds?, *Biological Invasions,* **16**(4): 935-947. Available at: https://www.scopus.com/inward/record.url?eid=2-s2.0-84896044201&partnerID=40&md5=57ba1514424f6015dc31bdee915624a3

Hitchen, D. J., Burgin, S., Ridgeway, P. and Wotherspoon, D., 2011. Habitat use by the jacky lizard Amphibolurus muricatus in a highly degraded urban area, *Animal Biology,* **61**(2): 185-197. Available at: https://www.scopus.com/inward/record.url?eid=2-s2.0-79957609501&partnerID=40&md5=01d17517434f46fa897c29c778cf04b7

Howland, B., Stojanovic, D., Gordon, I. J., Manning, A. D., Fletcher, D. and Lindenmayer, D. B., 2014. Eaten out of house and home: Impacts of grazing on ground-dwelling reptiles in Australian grasslands and grassy woodlands, *PLoS ONE,* **9**(12). Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84917705499&partnerID=40&md5=54eb66289d572768d9cd7924eccbca62

Howland, B. W. A., Stojanovic, D., Gordon, I. J., Fletcher, D., Snape, M., Stirnemann, I. A. and Lindenmayer, D. B., 2016. Habitat preference of the striped legless lizard: Implications of grazing by native herbivores and livestock for conservation of grassland biota, *Austral Ecology*: n/a-n/a. Available at: http://dx.doi.org/10.1111/aec.12337

http://onlinelibrary.wiley.com/store/10.1111/aec.12337/asset/aec12337.pdf?v=1&t=injkt7qy&s=30b24ba3dc6cbd53351e860c789f7af23f67b0a8

Huey, R. B., Losos, J. B. and Moritz, C., 2010. Are Lizards Toast?, *Science,* **328**(5980): 832-833. Available at: http://science.sciencemag.org/content/sci/328/5980/832.full.pdf

IUCN/SSC, 2013. *Guidelines for Reintroductions and Other Conservation Translocations,* IUCN Species Survival Commission, Gland, Switzerland.

Kirkpatrick, J., McDougall, K. and Hyde, M., 1995. *Australia's most threatened ecosystem: the southeastern lowland native grasslands,* Surrey Beatty & Sons in association with the World Wide Fund for Nature Australia, NSW, Australia.

Knox, C. D. and Monks, J. M., 2014. Penning prior to release decreases post-translocation dispersal of jewelled geckos, *Animal Conservation,* **17**: 18-26. Available at: http://dx.doi.org/10.1111/acv.12149

http://onlinelibrary.wiley.com/store/10.1111/acv.12149/asset/acv12149.pdf?v=1&t=io6s04dc&s=1a130bf80f60e302eef77136b049245fe81b3607

Kukolic, K., McElhinney, N. and Osborne, W., 1994. *Survey for the Striped Legless Lizard Delma impar during 1993 in the proposed development area E1 comprising sites for the Gungahlin Town Centre and the suburb of Franklin. Internal Report 94/3,* ACT Parks and Conservation Service, Canberra.

Kutt, A., 1993. A preliminary evaluation of the use of fluorescent pigments to track the movements of the Striped Legless Lizard *Delma impar* (Reptilia: Pygopodidae), In *Herpetology in Australia. A Diverse Discipline* (Eds, Lunney, D. and Ayers, D.) Royal Zoological Society of New South Wales, NSW, pp. 179-183.

Kutt, A. S., Coulson, G. and Wainer, J., 1998. Diet of the Striped Legless Lizard Delma impar (Squamata: pygopodidae) in a western (basalt) plains grassland, Victoria, *Australian Zoologist,* **30**(4): 412-418. Available at: http://publications.rzsnsw.org.au/doi/abs/10.7882/AZ.1998.007

Lovegrove, T. G., 1996. Island releases of saddlebacks Philesturnus carunculatus in New Zealand, *Biological Conservation,* **77**(2–3): 151-157. Available at: http://www.sciencedirect.com/science/article/pii/0006320796000067

Martin, L. J. and Murray, B. R., 2011. A predictive framework and review of the ecological impacts of exotic plant invasions on reptiles and amphibians, *Biological Reviews*, **86**(2): 407-419. Available at: https://www.scopus.com/inward/record.url?eid=2-s2.0-79954555993&partnerID=40&md5=258a03cfb4183c4ffa6132fa991b7b58

http://onlinelibrary.wiley.com/store/10.1111/j.1469-185X.2010.00152.x/asset/j.1469-185X.2010.00152.x.pdf?v=1&t=inh7d755&s=38db0b6629c7e8be07a4b1d02822ef6b5fa66e1f

McCoy, E. D., Osman, N., Hauch, B., Emerick, A. and Mushinsky, H. R., 2014. Increasing the chance of successful translocation of a threatened lizard, *Animal Conservation*, **17**: 56-64. Available at: http://dx.doi.org/10.1111/acv.12145

http://onlinelibrary.wiley.com/store/10.1111/acv.12145/asset/acv12145.pdf?v=1&t=idz8hrq4&s=9903344375e488c9fe26b2c1d377c72e135ced3c

Michael, D. R., Cunningham, R. B., Donnelly, C. F. and Lindenmayer, D. B., 2012. Comparative use of active searches and artificial refuges to survey reptiles in temperate eucalypt woodlands, *Wildlife Research*, **39**(2): 149.

Miller, K. A., Bell, T. P. and Germano, J. M., 2014. Understanding publication bias in reintroduction biology by assessing translocations of New Zealand's Herpetofauna, *Conservation Biology*, **28**(4): 1045-1056. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84904752713&partnerID=40&md5=e22abab23ea0849a82fd9fae6285dcbd

http://onlinelibrary.wiley.com/store/10.1111/cobi.12254/asset/cobi12254.pdf?v=1&t=idiblx6y&s=251948d5dbbab470a7e8edd059178caa8e28c9b6

Moseby, K. E., Read, J. L., Paton, D. C., Copley, P., Hill, B. M. and Crisp, H. A., 2011. Predation determines the outcome of 10 reintroduction attempts in arid South Australia, *Biological Conservation*, **144**(12): 2863-2872. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-83555164834&partnerID=40&md5=4ae056e578cf9b94cdadaed49c02d3fd

http://ac.els-cdn.com/S0006320711003119/1-s2.0-S0006320711003119-main.pdf?_tid=9c089fbc-462c-11e5-b896-00000aab0f27&acdnat=1439959491_49b8552a11c5a5ab00277c1a1a274ac4

Nunan, D., 1995. *Diet and feeding ecology of the striped legless lizard Delma impar (Fischer, 1882) within the Australian Capital Territory*, Unpublished report to the ACT Parks and Conservation Service, Canberra, University of Canberra, Canberra.

O'Shea, M., 2013. *Evaluating the effectiveness of salvage and translocation of Striped Legless Lizards*, Technical Report Series No. 243, Arthur Rylah Institute for Environmental Research Department of Sustainability and Environment, Heidelberg, Victoria.

O'Shea, M. B., 2005. 'Methods for assessment and techniques for management of striped legless lizard *Delma impar* populations in South-eastern Australia', PhD thesis, Sustainability Group, Victoria University, Australia.

OEH, 2015. *Little Whip Snake - profile*, NSW Government Office of Environment and Heritage. Available at: http://www.environment.nsw.gov.au/threatenedSpeciesApp/profile.aspx?id=10774 (accessed 12/05/2016).

Osmond, H., 1994. 'Habitat Specialisation and the Isolation of Remnant Populations of the Striped Legless Lizard, *Delma Impar* (Pygopodidae): Temperature Preference, Metabolic and Allozyme Correlates of Activity in Lizards, with Particular Refernce to Fossorial Habit', Honours thesis, Australian National University, Canberra.

Parker, K. A., 2008. Translocations: Providing Outcomes for Wildlife, Resource Managers, Scientists, and the Human Community, *Restoration Ecology*, **16**(2): 204-209. Available at: http://dx.doi.org/10.1111/j.1526-100X.2008.00388.x

http://onlinelibrary.wiley.com/doi/10.1111/j.1526-100X.2008.00388.x/abstract

Parks Victoria, 2002. *Annual report for the field release of salvaged striped legless lizards (Delma impar)*, Parks Victoria,

Pérez, I., Anadón, J. D., Díaz, M., Nicola, G. G., Tella, J. L. and Giménez, A., 2012. What is wrong with current translocations? A review and a decision-making proposal, *Frontiers in Ecology and the Environment*, **10**(9): 494-501. Available at: http://dx.doi.org/10.1890/110175 (accessed 2015/07/29).

Platenberg, R. J. and Griffiths, R. A., 1999. Translocation of slow-worms (Anguis fragilis) as a mitigation strategy: A case study from south-east England, *Biological Conservation,* **90**(2): 125-132. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-0032984059&partnerID=40&md5=2ec9b86d6c05d8238691947ed8be2173

http://ac.els-cdn.com/S0006320799000233/1-s2.0-S0006320799000233-main.pdf?_tid=bf6062c0-40bd-11e5-a0f9-00000aab0f6c&acdnat=1439362120_39ec4ceb7fa565fa2e7bf338bd1219e3

Price, B., Kutt, A. S. and McAlpine, C. A., 2010. The importance of fine-scale savanna heterogeneity for reptiles and small mammals, *Biological Conservation,* **143**(11): 2504-2513. Available at: https://www.scopus.com/inward/record.url?eid=2-s2.0-77956877774&partnerID=40&md5=c3c80a7aa72b54dabdc37f7db00faa26

http://ac.els-cdn.com/S0006320710002831/1-s2.0-S0006320710002831-main.pdf?_tid=5a474d18-0b8d-11e6-ae12-00000aab0f02&acdnat=1461661421_186914bdaea562d9453dd874f34935b5

Read, J. L., Johnston, G. R. and Morley, T. P., 2011. Predation by snakes thwarts trial reintroduction of the endangered woma python aspidites ramsayi, *Oryx,* **45**(4): 505-512. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-80955158544&partnerID=40&md5=d980cf434f8ab6b4c088bd3e49a92620

http://journals.cambridge.org/action/displayFulltext?pageCode=100101&type=1&fid=8429117&jid=ORX&volumeId=45&issueId=04&aid=8429115&fromPage=online

Richards, J. D. and Short, J., 2003. Reintroduction and establishment of the western barred bandicoot Perameles bougainville (Marsupialia: Peramelidae) at Shark Bay, Western Australia, *Biological Conservation,* **109**(2): 181-195. Available at: http://www.sciencedirect.com/science/article/pii/S0006320702001404

Rieder, J. P., Newbold, T. A. S. and Ostoja, S. M., 2010. Structural changes in vegetation coincident with annual grass invasion negatively impacts sprint velocity of small vertebrates, *Biological Invasions,* **12**(8): 2429-2439. Available at: https://www.scopus.com/inward/record.url?eid=2-s2.0-77954458842&partnerID=40&md5=d0c10050bf5bd4a41d90829d89b85551

Robertson, P. and Smith, W., 2010. *National Recovery Plan for the Striped Legless Lizard, Delma impar*, Victorian Government Department of Sustainability and Environment, Melbourne.

Roe, J. H., Frank, M. R., Gibson, S. E., Attum, O. and Kingsbury, B. A., 2010. No place like home: an experimental comparison of reintroduction strategies using snakes, *Journal of Applied Ecology,* **47**(6): 1253-1261. Available at: http://dx.doi.org/10.1111/j.1365-2664.2010.01886.x

http://onlinelibrary.wiley.com/store/10.1111/j.1365-2664.2010.01886.x/asset/j.1365-2664.2010.01886.x.pdf?v=1&t=id8eynks&s=01e8b799401e9271a7daf06e1b3bd95934aa4ba9

Sato, C. F., Wood, J. T., Schroder, M., Green, K., Osborne, W. S., Michael, D. R. and Lindenmayer, D. B., 2014. An experiment to test key hypotheses of the drivers of reptile distribution in subalpine ski resorts, *Journal of Applied Ecology,* **51**(1): 13-22. Available at: http://dx.doi.org/10.1111/1365-2664.12168

Seddon, P. J., Armstrong, D. P. and Maloney, R. F., 2007. Developing the Science of Reintroduction Biology

Desarrollando la Ciencia de Biología de la Reintroducción, *Conservation Biology,* **21**(2): 303-312. Available at: http://dx.doi.org/10.1111/j.1523-1739.2006.00627.x

Seddon, P. J., Griffiths, C. J., Soorae, P. S. and Armstrong, D. P., 2014. Reversing defaunation: Restoring species in a changing world, *Science,* **345**(6195): 406-412. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84904793772&partnerID=40&md5=f52d79d1b7176f2cad3a22c546e3e033

Seddon, P. J., Soorae, P. S. and Launay, F., 2005. Taxonomic bias in reintroduction projects, *Animal Conservation,* **8**(1): 51-58. Available at: http://dx.doi.org/10.1017/S1367943004001799

http://onlinelibrary.wiley.com/store/10.1017/S1367943004001799/asset/S1367943004001799.pdf?v=1&t=igq38hzq&s=456ad0889916d14236aff06303a1e864da11bf74

Sheean, V. A., Manning, A. D. and Lindenmayer, D. B., 2012. An assessment of scientific approaches towards species relocations in Australia, *Austral Ecology*, **37**(2): 204-215. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84858860333&partnerID=40&md5=1ffbb081a0159b04106794ade39743b2

http://onlinelibrary.wiley.com/store/10.1111/j.1442-9993.2011.02264.x/asset/j.1442-9993.2011.02264.x.pdf?v=1&t=idib3ydn&s=bd533d29915902a84e77b414afb7e39a1dcb3942

Short, J., 2009. *The characteristics and success of vertebrate translocations within Australia: a final report to Department of Agriculture, Fisheries and Forestry*,

Short, J. and Turner, B., 2000. Reintroduction of the burrowing bettong Bettongia lesueur (Marsupialia: Potoroidae) to mainland Australia, *Biological Conservation*, **96**(2): 185-196. Available at: http://www.sciencedirect.com/science/article/pii/S0006320700000677

Sinervo, B., Méndez-de-la-Cruz, F., Miles, D. B., Heulin, B., Bastiaans, E., Villagrán-Santa Cruz, M., Lara-Resendiz, R., Martínez-Méndez, N., Calderón-Espinosa, M. L., Meza-Lázaro, R. N., Gadsden, H., Avila, L. J., Morando, M., De la Riva, I. J., Sepulveda, P. V., Rocha, C. F. D., Ibargüengoytía, N., Puntriano, C. A., Massot, M., Lepetz, V., Oksanen, T. A., Chapple, D. G., Bauer, A. M., Branch, W. R., Clobert, J. and Sites, J. W., 2010. Erosion of Lizard Diversity by Climate Change and Altered Thermal Niches, *Science*, **328**(5980): 894-899. Available at: http://science.sciencemag.org/content/sci/328/5980/894.full.pdf

Spellerberg, I., 1972. Temperature tolerances of Southeast Australian reptiles examined in relation to reptile thermoregulatory behaviour and distribution, *Oecologia*, **9**(1): 23-46. Available at: http://dx.doi.org/10.1007/BF00345241

Sullivan, B. K., Nowak, E. M. and Kwiatkowski, M. A., 2015. Problems with mitigation translocation of herpetofauna, *Conservation Biology*, **29**(1): 12-18. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84921436490&partnerID=40&md5=3b0a883ef5ca0e52aee553c083283611

http://onlinelibrary.wiley.com/store/10.1111/cobi.12336/asset/cobi12336.pdf?v=1&t=icmzug96&s=1559d132e5242ed012033a8c7cdfb0ee0df0c3f4

Thompson, M. J., 2006. 'The Use of Artificial Refuges to Census Populations of the ‘Threatened’ Striped Legless Lizard, *Delma impar* in Western Victoria', Department of Zoology, La Trobe University,

Towns, D. R. and Ferreira, S. M., 2001. Conservation of New Zealand lizards (Lacertilia: Scincidae) by translocation of small populations, *Biological Conservation*, **98**(2): 211-222. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-0035089925&partnerID=40&md5=18c8f1caeaa241d89919b383b973814f

http://ac.els-cdn.com/S0006320700001567/1-s2.0-S0006320700001567-main.pdf?_tid=c2873c26-40bd-11e5-84b6-00000aab0f6c&acdnat=1439362126_20a8116c5e61f17325be3e0a416f1c49

Webster, A., Fallu, R. and Preece, K., 2003. *Striped legless lizard Delma impar action statement #17*, Department of Sustainability and Environment, East Melbourne, Victoria.

Appendix 1: Sample statistical model output

Hierarchical generalized linear model

Response variate: Lizard_presence_11Oct_removed
Binomial totals: 1

Mean model

Fixed terms: Complexity_stand2.Dominant_grass_vegetation
Distribution: binomial
Link: logit
Random terms: Grid_Enclosure
Distribution: beta
Link: logit
Dispersion: free

Dispersion model

Distribution: gamma
Link: logarithm

Estimates from the mean model

Estimates of parameters

```
                                                                          antilog of
Parameter                                    estimate        s.e.    t(128)    estimate
constant                                       -0.882       0.308     -2.86      0.4140
Complexity_stand2.Dominant_grass_vegetation ALG
                                                0.408       0.404      1.01       1.504
Complexity_stand2.Dominant_grass_vegetation KG
                                                1.083       0.530      2.04       2.954
Grid_Enclosure F1                              -0.200       0.250     -0.80      0.8184
Grid_Enclosure F2                              -0.032       0.248     -0.13      0.9686
Grid_Enclosure F3                               0.090       0.244      0.37       1.094
Grid_Enclosure F4                               0.142       0.246      0.58       1.152
```

```
Parameters for factors are differences compared with the reference level:
                  Factor    Reference level
          Grid_Enclosure    F1
```

Estimates from the dispersion model

Estimates of parameters

```
                                                                   antilog of
Parameter                               estimate        s.e.      t(*)    estimate
phi                                        0.127       0.125      1.01       1.135
lambda Grid_Enclosure                      -3.95        1.49     -2.65     0.01932
```

Likelihood statistics

```
-2 × h(y|v)                    160.380
-2 × h                         158.425
-2 × Pv(h)                     162.710
-2 × Pβ,v(h)                   163.027
-2 × EQD(y|v)                  149.814
-2 × EQD                       136.730
-2 × Pv(EQD)                   141.015
-2 × Pβ,v(EQD)                 141.332

Fixed parameters in mean model           3
Random parameters in mean model          4
Fixed dispersion parameters              2
Random dispersion parameters             0
```

Wald tests for dropping HGLM fixed terms

```
                                     Term     Wald statistic     d.f.     approx. pr.
    Complexity_stand2.Dominant_grass_vegetation          6.129        2           0.047
```

Predictions from a hierarchical generalized linear model

These predictions are estimated mean proportions, formed on the scale of the response variable.

The predictions have been formed only for those combinations of factor levels for which means can be estimated without involving aliased parameters.

The predictions are at the mean value of the distribution of any random term whose factor levels have not all been fixed.

The standard errors are appropriate for interpretation of the predictions as summaries of the data rather than as forecasts of new observations.

```
 Dominant_grass_vegetation          ALG                        KG
                            predictions          se   predictions          se
         Complexity_stand2
                      -2.5        0.130       0.136         0.027       0.033
                      -2.0        0.155       0.131         0.045       0.044
                      -1.5        0.183       0.122         0.075       0.054
                      -1.0        0.216       0.106         0.123       0.058
                      -0.5        0.252       0.085         0.194       0.054
                       0.0        0.293       0.064         0.293       0.064
                       0.5        0.337       0.059         0.416       0.111
                       1.0        0.384       0.084         0.550       0.169
                       1.5        0.433       0.126         0.678       0.203
                       2.0        0.484       0.174         0.783       0.201
                       2.5        0.534       0.220         0.861       0.172
```

Message: s.e's, variances & lsd's are approximate, since the model is not linear.