Revegetation, restoration and reptiles in rural landscapes: insights from long-term monitoring programs in the temperate eucalypt woodlands of south-eastern Australia.

Damian R. Michael, Mason Crane, Daniel Florance and David B. Lindenmayer

Damian R. Michael, Mason Crane, Daniel Florance are Senior Research Officers and David B. Lindenmayer is Professor in Ecology at the Fenner School of Environment and Society (Hancock Building (43), Biology Place, Australian National University, Canberra, ACT 0200, Australia, Tel: +61 2 61250654; Email: damian.michael@anu.edu.au). The research arose due to a lack of information pertaining to the response of reptiles to revegetation and restoration in Australian agricultural landscapes.

Summary

Over the past decade there has been a concerted effort to better understand the distribution and abundance of reptiles in agricultural landscapes, and to specifically evaluate their response to revegetation (tree and shrub plantings) and habitat restoration in the wheat-sheep belt of south-eastern Australia. This paper reviews the response of reptiles to revegetation and woodland management and provides ten insights and lessons that can be applied to help improve reptile conservation in temperate eucalypt woodlands and fragmented agricultural landscapes in Australia. The review focuses primarily on revegetation programs conducted by Landcare and Greening Australia, and management interventions funded by Local Land Services in NSW and Catchment Management Authorities in Victoria.

Keywords: biodiversity, farm management, long-term research, reptiles, temperate woodlands, woodland restoration

Introduction

Ecological information collected on a repeat basis provides valuable insights into how landscape patterns and ecological processes change over time (Lindenmayer & Likens 2010). This knowledge is fundamental for understanding the status of the life support systems of the planet. However, long-term biodiversity monitoring programs are rare for many ecosystems worldwide (Lindenmayer & Likens 2010). Over the past decade, several large-scale, biophysical monitoring programs have been established in the temperate eucalypt woodlands of south-eastern Australia, a region that spans approximately 1200 km from north to south and covers an area approximately the size of Finland. The response of reptiles to habitat restoration, revegetation (primarily tree and shrub plantings) and landscape transformation has been a key component of these biophysical monitoring programs. Previous literature reviews on faunal response to revegetation in agricultural landscapes highlighted a concerning lack of studies on reptile fauna (Munro *et al.* 207; Ryan 1999). Over the past ten years, there has been a concerted effort to address this gap in the ecological literature. Currently, there are a number of studies that have made a significant contribution to better understanding the distribution and abundance of reptiles in agricultural landscapes, and their response to habitat restoration and ecological plantings in the wheat-sheep belt of south-eastern Australia. The aim of this short review is to summarise some of the key findings from the latest research and provide ten insights and lessons that can be applied to help improve reptile conservation in fragmented agricultural landscapes.

#1 Old growth native vegetation is key to preserving reptile diversity on farms

There is now compelling evidence on a global-scale that many reptile species have experienced severe range contractions and population declines due to habitat loss and fragmentation (Gibbon *et al.* 2000), with many species occurring in agricultural landscapes at considerable risk of local extinction (Brown *et al.* 2008; Driscoll 2004). The premise of protecting old growth vegetation has long been regarded as a key principle in conservation biology and ecosystem management, primarily because old growth habitats, particularly along roadsides, have more complex vegetation structure (Brown *et al.* 2008). Stands of old growth vegetation also support more rare species and taxa dependant on advanced habitat characteristics than early-successional habitats (Driscoll 2004; Lindenmayer & Franklin 2002). One study compared the number of reptile species on farms with differing amounts of native vegetation cover. This study found significantly more reptile species were detected on farms with higher amounts of native vegetation compared to farms with lower amounts of native vegetation (mean 4.7 species/farm *c.f.* 3.6 species/farm) (Cunningham *et al.* 2007). Furthermore, an increase of 0.24 reptile species/ha was found for an increase of 1% in density of trees >50 cm diameter, and a 6% increase in reptile species was detected with a 10% increase in the area of remnant native vegetation on farms (Cunningham *et al.* 2007).

The importance of remnant native vegetation for preserving reptile diversity on farms was further supported in a study which examined microhabitat guild affiliation in 52 reptile species across the Box Gum Grassy woodland ecosystem. This study showed that over 50% of all reptile species detected in this region belonged to guilds associated with old growth vegetation attributes such as mature trees and fallen timber (Michael *et al.* 2015). Regrowth woodlands also provide valuable habitat for reptiles (Bruton *et al.* 2013), and these areas need better protection to ensure vegetation communities reach maturity (McAlpine *et al.* 2015). These findings have major implications for the protection of old growth and regrowth vegetation, including the protection of mature paddocks trees and the regulation of firewood collection. A key message from these studies is that the protection and appropriate management of successional vegetation stages, and associated resources (e.g. fallen timber and leaf litter) is critical for preserving reptile diversity on farms.

#2 Travelling Stock Reserves are fundamental for protecting abundant reptile populations

Travelling Stock Reserves (TSR) comprise a network of reserves and routes in New South Wales and in many cases provide examples of native vegetation that is relatively intact and in good condition (Lentini *et al.* 2011b). Their value in supporting high numbers of woodland birds and arboreal marsupials is well established (Davidson *et al.* 2005; Lentini *et al.* 2011a; Lindenmayer *et al.* 2012a; Lindenmayer *et al.* 2010b). Travelling Stock Reserves also play an important role in providing habitat for regionally rare reptile species (Michael & Lindenmayer 2010), and those near the limits of their geographical range (Michael *et al.* 2010a). One study compared reptile species richness and abundance between TSRs and other agricultural land uses across different threatened ecological vegetation communities: 1) Grey Box woodland, 2) Black Box woodland, 3) Boree woodland, and 4) Sandhill (Cypress Pine) woodland. This study found TSRs supported significantly higher numbers of small lizards compared to agricultural sites subject to heavy grazing pressure, sites subject to winter-only grazing and sites excluded from grazing (Michael *et al.* 2014). This study also found significantly higher numbers of Boulenger's Skink (*Morethia boulengeri*) and Ragged Snake-eyed Skink (*Cryptoblepharus pannosus*) on TSRs. In some vegetation types, these two semi-arboreal skink species (Michael *et al.* 2015) were twice as abundant in TSRs than on sites used for primary production purposes (e.g. Boulenger's Skink: mean 20 individuals/site in Grey Box Woodland *c.f.* mean 9 individuals/site in Grey Box Woodland), a result attributed to greater amounts of coarse woody debris in eucalypt dominated TSRs (Michael *et al.* 2014). To maintain common lizard species in rural landscapes, it is important that such areas continue to be appropriately managed and any potential threatening processes are avoided such as vegetation clearing, intensive and prolonged grazing by domestic livestock and inappropriate firewood collection.

#3 Reptile species richness is driven by habitat condition rather than land tenure *per se*

Agricultural landscapes comprise units of land under different tenure and management, with accompanying variation in tree cover and habitat condition. Livestock production is one of the primary enterprises in agricultural landscapes and refinements in grazing management have seen a shift towards rotational or pulse grazing practices (Dorrough *et al.* 2012). Several long-term studies have examined reptile species richness in relation to land tenure and land management. In north-east Victoria, reptile species richness was compared among woodland conservation reserves, rotationally grazed woodland remnants, and continuously grazed woodland remnants. This study found the mean number of reptile species did not differ significantly among land uses (Michael *et al.* 2016). This pattern also was evident from a study in southern NSW which examined reptile species richness among woodland remnants subject to varying levels of grazing pressure (Michael *et al.* 2014).

One hypothesis that has been suggested to explain the lack of tenure effects could be the prior filtering of reptile assemblages, resulting in habitat generalists dominating woodland reptile communities (Schutz & Driscoll 2008). This is plausible as over 40% of a suite of woodland reptile species in south-eastern Australia are classified as habitat specialists (Michael *et al.* 2015). Furthermore, occupancy patterns for many reptile species tend to be driven by site-scale habitat variables, including native plant diversity, coarse woody debris, surface rocks and habitat complexity (Garden *et al.* 2007a; Jellinek *et al.* 2004; Michael *et al.* 2014, 2017). Thus, grazing landscapes that support key habitat features have the potential to support a wide variety of reptile species (Fischer *et al.* 2005; Jellinek *et al.* 2014; Pulsford *et al.* 2017). An important management implication of this research will be for land managers to identify areas of high quality habitat within production areas and ensure vegetation condition is maintained or improved through appropriate grazing regimes.

#4 Rocky outcrops provide habitat refuges and landscape-scale connectivity

Exposures of granite, basalt and meta-sedimentary rocks are a common feature in agricultural landscapes (Fitzsimmons & Michael 2016). Large, inaccessible rocky outcrops often support important stands of native vegetation, whereas small or low lying rocky outcrops are often cleared and degraded (Norris & Thomas 1991; Michael & Lindenmayer 2012). Despite the loss of native vegetation, small-sized rocky outcrops in agricultural landscapes support high diversity of reptile species (Michael *et al.* 2008), including specialist rock-dwelling species

(Michael *et al.* 2010b) and top predators such as carpet pythons (Michael & Alexander 2015; Michael & Lindenmayer 2008). Rocky outcrops also provide habitat generalists with available shelter and protection from predators. Key insights from research on granite outcrops in the South-west Slopes bioregion of NSW includes: a) large, structurally complex rocky outcrops support more reptile diversity compared to small, structurally simple rocky outcrops (Michael *et al.* 2008); b) the presence of rocky outcrops or surface rocks has a significant additive effect on reptile species richness in woodland remnants (Michael *et al.* 2011a); c) heavy shading caused by vigorous eucalypt regeneration or dense tree plantings can reduce basking sites for rock-dwelling reptile species (Michael *et al.* 2011a); d) the microhabitat requirements of common lizard species in rocky environments may differ from their microhabitat requirements in other environments (Michael *et al.* 2010b); and e) rocky outcrops may play an important role in the evolution of sociality in some lizard assemblages (Michael *et al.* 2010c). The protection and rehabilitation of this important habitat is essential to the preservation of reptile diversity in agricultural landscapes. However, rocky outcrops need to be managed and restored appropriately to achieve positive conservation outcomes (Hussey 1998; Michael *et al.* 2010d).

#5 Ecological tree plantings provide habitat for a subset of woodland reptile species

Millions of dollars are spent annually on restoration and revegetation programs in Australia - particularly ecological tree and shrub plantings in agricultural landscapes that aim to combat salinity, provide shelter for livestock and reverse the loss of habitat (Vesk and Mac Nally 2006). While the response of woodland birds to such programs is largely positive (Lindenmayer *et al.* 2010a; Vesk *et al.* 2008), the response of reptiles to ecological revegetation programs has received far less attention (Munro *et al.* 207; Ryan 1999). Kavanagh *et al.* (2005) found tree plantations on farmland provided little useful habitat for reptiles, whereas Jellinek *et al.* (2014) found reptile species richness and counts did not substantially differ between revegetated, remnant and cleared habitats, or between linear strip and patch treatments. However, mean species richness and abundance was low across all treatments in this study.

Another study reported reptile diversity to be low in landscapes with high amounts of tree plantings (Cunningham *et al.* 2007), a result largely due to historical clearing and widespread declines in reptile diversity in agricultural landscapes. On average, tree plantings that were at least ten years old supported 0.84 fewer reptile species per ha than old growth remnants (Michael *et al.* 2011a), although species composition varied between growth types. Of the reptile species consistently found in tree plantings, the majority were classified as habitat generalists, species adapted to living in grassland environments, or those capable of dispersing through grazing landscapes. Species assemblages found in remnants consist of more habitat specialists and rare taxa (Jellinek *et al.* 2014). Ground cover condition may influence reptile use of revegetated areas. For example, of the few species detected in tree plantings, the Southern Rainbow Skink (*Carlia tetradactyla*) and Olive Legless Lizard (*Delma inornata*), were more frequently observed in ungrazed tree plantings than in grazed remnants (Michael *et al.* 2011b), a pattern suggestive of an effect of the accumulation of leaf litter and tussock grasses cover that form in the absence of heavy herbivory pressure.

Tree and shrub plantings typically support a high density of stems, canopy cover and shade levels, attributes which are generally not favoured by heliothermic (sun-loving) reptiles. Not surprisingly, a perverse effect of dense tree plantings around rocky outcrops is lower diversity of a subset of these - specialist rock-dwelling (saxicolous) reptile species - a pattern we attribute to a reduction in the quality of thermally suitable basking sites. Conversely reptiles that prefer moist, shaded environments (thigmothermic species) do respond positively to dense tree plantings. A case in point is the soil-dwelling Three-toed Earless Skink (*Hemiergis talbingoensis*) which has benefited from revegetation in the South West Slopes of NSW (Michael *et al.* 2010b). Future revegetation programs should therefore consider the life-history attributes of regional reptile faunas to ensure a broad range of thermally suitable environments and microhabitats are created. Ecological tree plantings also need to focus on improving ground layer structure by establishing shrubs and native grasses (Jellinek *et al.* 2014).

#6 Woodland remnants may support greater reptile species richness after management

Many different agri-environment schemes have been adopted by natural resource management agencies to improve the condition and extent of threatened woodland remnants, including scattered trees. Programs such as the Environmental Stewardship Program paid landholders to adopt environmentally sustainable agricultural practices (Lindenmayer *et al.* 2012b). Actions like restricting livestock grazing, applying rotational or winter-only grazing regimes, restricting the removal of coarse woody debris, and controlling pest plants and animals are some of the key management interventions being trialled. One study found woodland remnants placed under an environmental stewardship agreement supported a similar number of reptile species compared to adjacent control sites that remained unchanged from the status quo. Reptile species richness also differed significantly across natural resource management regions. For example, woodland sites under stewardship agreements in southern Queensland supported on average four times more species than woodland stewardship sites in southern New South Wales (Lindenmayer *et al.* 2012b), a result attributed to differences in climate and historical land clearing. Several other studies comparing reptile species richness at the commencement and several years into management intervention programs failed to detect significant differences among treatments - with production areas and areas managed for conservation supporting similar numbers and abundance of reptile species (Michael *et al.* 2014; Michael *et al.* 2016). These findings suggest that grazing management alone may not benefit reptiles in the short-term, a finding consistent with other studies (Brown *et al.* 2011; Dorrough *et al.* 2012). Additional metrics that influence reptile occurrence (e.g. elevation and topography) may need to be considered in future stewardship and incentive delivery schemes to ensure maximum levels of reptile diversity in agricultural landscapes are conserved (Brown et al. 2011; Kay *et al.* 2016).

#7 Site-scale habitat manipulations benefit reptiles with specific life-history attributes

Approximately 80 reptile species are associated with the temperate eucalypt woodlands of south-eastern Australia (Wilson & Swan 2013). This assemblage includes rock-dwelling species, tree-dwelling species, terrestrial species and those associated with ground cover attributes such as leaf litter and native grasslands or certain soil types. Previous studies have found that ecological tree and shrub plantings benefit only a subset of reptile species, and suitable habitats may take many years to develop before faunal responses are evident (Vesk *et al.* 2008). Actively restoring key habitat elements may prove to be a cost-effective input for improving numbers of particular reptile species in relatively short time-frames. For example, the introduction of natural and artificial rocks to degraded sandstone escarpments can improve numbers of a threatened snake species and its prey (Croak *et al.* 2013, 2014; Goldingay & Newell 2017), and the translocation of basalt rock to an urban grassland reserve on the outskirts of Canberra resulted in colonisation by the threatened Pink-tailed Worm-lizard (*Aprasia parapulchella*) and associated ant prey (McDougall *et al.* 2016). Another study in the ACT found that several habitat generalist lizard species increased in abundance following the establishment of large amounts of coarse woody debris to a degraded grassy woodland (Manning *et al.* 2013). These studies indicate that some reptile species are responsive to direct habitat manipulations, suggesting restoration programs should consider adding rock habitat. Future studies should also focus on experimentally manipulating micro-habitats to improve abundance and dispersal opportunities for different species. This concept aligns with the evolution of a greater sophistication of management interventions that are now more consistent with the National Standards for 'ecological restoration' which encourages micro-habitat manipulations and improved restoration planning for biodiversity conservation (McDonald *et al.* 2016).

#8 Landscape-scale changes in vegetation cover drive temporal changes in reptile abundance

The conversion of agricultural land to forest plantations is a major driver of global land use change (Foley *et al.* 2005). One study used a large-scale long-term landscape transformation experiment to examine reptile response to the establishment of pine plantations on previously grazed temperate woodlands. At the commencement of the study, no statistical difference in the probability of occurrence or abundance of reptiles between woodland remnants surrounded by grazing land compared to woodland remnants surrounded by pine plantations was detected (Lindenmayer*, et al.* 2001). After six years of investigation, the number of species recorded in the study area had doubled and several species reported a significant temporal linear increase, including the Southern Rainbow Skink (*C. tetradactyla*) and Three-toed Earless Skink (*H. talbingoensis*), terrestrial and fossorial species respectively (Lindenmayer *et al.* 2008). After 16 years of investigation, the probability of the Three-toed Earless Skink colonising remnants surrounded by pine plantations continued to increase over time, whereas the probability of the Southern Rainbow Skink colonising remnants surrounded by pine plantations decreased (Mortelliti *et al.* 2015). Key differences in life-history traits such as mode of thermoregulation were postulated as reasons for explaining the trend patterns. Such findings indicate that landscape-scale changes in forest cover can influence different species in different ways, and may take decades before extinction is noticed. A key issue in understanding temporal changes in reptile numbers is uncoupling the interactive effects of climate from land use change. Periods of prolonged drought, followed by several above average years of rainfall can produce significant spikes in reptile abundance and detection probabilities (Michael *et al.* 2016). Only through adequately funded long-term monitoring programs can the interactive effects of weather be uncoupled from land management and land use practices.

#9 Collecting baseline information on private property is vital for advancing science

Reptiles are one of the most species-rich groups of vertebrates in the world. Over 1000 species have been described in Australia and this far outnumbers any other group of Australian vertebrates (Cogger 2014; Wilson & Swan 2013). Recent advances in Australian taxonomy over the past decade has culminated in hundreds of new species being described. With the number of new species increasing annually and refinements in the knowledge of species range limits, collecting baseline data and compiling species inventories is paramount for understanding population trends and evaluating conservation status. Information collected on private property is extremely important because agricultural enterprises constitute more than 50% of Australia's land use. Furthermore, the national reserve system is not representative of all vegetation communities found in agricultural regions. The temperate eucalypt woodlands of south-eastern Australia support approximately 10% of all known reptile species. Given the size of this region (pre-1750 extent, approximately 5,011,655 ha), this is not a particularly rich number of species by Australian standards, but the region supports many threatened species as well as the critically endangered ecological vegetation community Box Gum Grassy Woodland (BGGW). One study recorded 69 reptile species on private property across the BGGW ecosystem, approximately 62% of all species predicted to occur in this region (Kay *et al.* 2013). Similarly, a study in threatened woodland ecosystems in the Riverina bioregion of southern New South Wales detected 31 reptile species in agricultural landscapes (Michael *et al.* 2011b). Long-term surveys can significantly increase the knowledge of species distributions and geographical range limits for poorly documented species (Michael & Lindenmayer 2008, 2010, 2011). Greater commitment to funding monitoring programs and partnerships with landholders are required to further refine the knowledge of species distributions and conservation status of reptiles on private property.

#10 Selecting appropriate survey methods is critical for increasing detection rates

A wide variety of survey methods are used by researchers to document reptile occurrence and abundance (McDiarmid 2012). A common outcome of studies on reptiles is that a combination of survey methods is required to adequately sample all species and overcome issues associated with the detection of rare species (Doan 2003; Friend *et al.* 1989; Garden *et al.* 2007b). Traditional approaches to surveying reptiles have include using pit-fall traps (Friend *et al.* 1989; Gamble 2003; Moseby & Read 2001), funnel traps (Fitch 1951; Greenberg *et al.* 1994; Thompson & Thompson 2007), artificial covers and substrates (Hampton 2007; Lettink & Cree 2007; Michael *et al.* 2004), and active searches of natural habitat (Brown & Nicholls 1993; Michael *et al.* 2012). In recent years, the effectiveness of camera traps also has been trialled (Welbourne *et al.* 2015). While many of these methods have proven to be effective in detecting common and cryptic species in short-term studies, their utility in long-term monitoring studies for all groupings is not well established. Furthermore, their use in environments subject to agricultural disturbances (e.g. livestock grazing) is often impractical. To overcome the need to survey reptile communities on a repeat basis across a large number of sites and over broad geographical areas, a method was developed to monitor reptiles involving arrays of different artificial refuges (roofing tiles, railway sleepers and corrugated steel) in combination with time-constrained active searches of natural habitat (Michael *et al.* 2012). These findings indicate that large, diurnal and arboreal species are detected more frequently during active searches (and visual encounters), whereas fossorial, nocturnal and cryptic species are detected more frequently beneath artificial refuges. Other primary survey techniques such as drift fence arrays with pitfall and/or funnel traps may obtain higher abundance estimates (Hutchens and DePerno (2009). However, selecting cost-effective and reliable surveys methods is critical for detecting underlying trends patterns and response to ecological restoration and management.

General Conclusions

Many of the insights and lessons presented in this short summary are based on almost 20 years of long-term monitoring of reptile communities in agricultural landscapes by researchers from the Australian National University. Encouragingly, there is an increasing number of ecological studies being conducted on reptiles in agri-landscapes by other research institutions. Strong partnerships, collaborations with natural resource management organisations and landholders and access to funding is key to keeping long-term studies going. What is clear from the work presented in this short review, is that reptile diversity is comparatively low in agricultural regions, and many species are rare and patchily distributed across the landscape. Various studies have found that only a small number of reptile species are numerically abundant in any given area. Given that reptiles are an integral part of healthy and functional ecosystems, an important objective of sustainable farming enterprises will be to ensure common lizard species remain common into the future, and actions are taken to ensure populations of naturally rare species remain intact. This may involve more strategic placement of habitat corridors and using more advanced approaches to ecological restoration including focusing on micro-habitat manipulations (McDonald *et al.* 2016). Revegetation is now more than just tree planting, and includes restoring landscapes for a number of different reasons (e.g. ecological restoration, biodiversity offsets, agro-forestry and carbon credits) in a number of different ways (direct seeding, aerial seedling, tubestock planting and grazing manipulations), and using a wider variety of plant species (e.g. trees, shrubs, grasses and forbs). More studies are needed to monitor and evaluate novel ways to restore degraded landscapes for a broader suite of biodiversity.

Increased survey effect on private property and ongoing partnerships with landholders and natural resource management agencies will significantly improve knowledge on the distribution and abundance of reptiles in rural landscapes. However, there is urgent need to develop conservation programs on private property that specially focus on reptile fauna and their habitat requirements. Greater emphasis on protecting key habitat attributes such as old growth vegetation, isolated paddock trees, native grasslands, fallen timber, bush rock and rocky outcrops is required to enhance conservation outcomes for reptiles. The value of managing even relatively small areas of key reptile habitat within production areas needs better recognition, and future financial incentive schemes should focus on protecting and improving these parts of the landscape. There is also a need to determine how to effectively revegetate habitats for different reptile species to overcome dispersal barriers and improve habitat connectivity and population recovery following routine agricultural activities.

Acknowledgments

We thank the many organizations that have provided financial or logistic support. These include the National Environmental Science Programme Threatened Species Recovery Hub, Australian Research Council, Murray Local Land Services, Riverina Local land Services, North East Catchment Management Authority, Goulburn Broken Catchment Management Authority, Holbrook Landcare Network, NSW Environment Trust, Ian Potter Foundation and the Vincent Fairfax Family Foundation. We thank members of our field team for assisting with data collection, Christopher MacGregor, David Blair, Lachlan McBurney, Thea O'Loughlin, David Smith, Clare Crane, Sachiko Okada and Rebecca Montague-Drake.

References

Brown G. and Nicholls A. (1993) Comparative census techniques and modelling of habitat utilization by reptiles in northern Victoria. In: Lunney, D., Ayers, D. (Eds). *Herpetology in Australia: a Diverse Discipline*. Mosman: Royal Zoological Society of New South Wales, pp. 283-290.

Brown G. W., Bennett A. F. and Potts J. M. (2008) Regional faunal decline - reptile occurrence in fragmented rural landscapes of south-eastern Australia. *Wildlife Research* **35**, 8-18.

Brown G. W., Dorrough J. W. and Ramsey D. S. (2011) Landscape and local influences on patterns of reptile occurrence in grazed temperate woodlands of southern Australia. *Landscape and Urban Planning* **103**, 277-288.

Bruton M. J., McAlpine C. A. and Maron, M. (2013) Regrowth woodlands are valuable habitat for reptile communities. *Biological Conservation* **165**, 95-103.

Cogger H. (2014) *Reptiles and Amphibians of Australia*. CSIRO Publishing, Collingwood, Melbourne.

Croak B. M., Webb J. K. and Shine, R. (2013) The benefits of habitat restoration for rock-dwelling velvet geckos Oedura lesueurii. *Journal of Applied Ecology* **50**, 432-439.

Croak B. M., Pike D. A., Webb J. K. and Shine, R. (2010) Using artificial rocks to restore nonrenewable shelter sites in human-degraded systems: colonization by fauna. *Restoration Ecology* 18, 428-438.

Cunningham R. B., Lindenmayer D. B., Crane M., Michael D. and MacGregor C. (2007) Reptile and arboreal marsupial response to replanted vegetation in agricultural landscapes. *Ecological Applications* **17**, 609-619.

Davidson I., Scammell A., O'Shannassy P., Mullins M. and Learmonth S. (2005) Travelling stock reserves: refuges for stock and biodiversity? *Ecological Management & Restoration* **6**, 5-15.

Doan T. M. (2003) Which methods are most effective for surveying rain forest herpetofauna? *Journal of herpetology* **37**, 72-81.

Dorrough J., McIntyre S., Brown G., Stol J., Barrett G. and Brown A. (2012) Differential responses of plants, reptiles and birds to grazing management, fertilizer and tree clearing. *Austral Ecology* **37**, 569-582.

Driscoll D. A. (2004) Extinction and outbreaks accompany fragmentation of a reptile community. *Ecological Applications* **14**, 220-240.

Fischer J., Fazey I., Briese R. and Lindenmayer D. B. (2005) Making the matrix matter: challenges in Australian grazing landscapes. *Biodiversity & Conservation* **14**, 561-578.

Fitch H. S. (1951) A simplified type of funnel trap for reptiles. *Herpetologica* **7**, 77-80.

Fitzsimons J. A. and Michael D. R. (2016) Rocky outcrops: a hard road in the conservation of critical habitats. *Biological Conservation* **211**, 36-44.

Foley J. A., DeFries R., Asner G. P., Barford C., Bonan G., Carpenter S. R., Chapin F. S., Coe M. T., Daily G. C. and Gibbs H. K. (2005) Global consequences of land use. *Science* **309**, 570-574.

Friend G., Smith G. T., Mitchell D. and Dickman C. (1989) Influence of pitfall and drift fence design on capture rates of small vertebrates in semi-arid habitats of Western-Australia. *Wildlife Research* **16**, 1-10.

Gamble L. R. (2003) Comparative effectiveness of two trapping techniques for surveying the abundance and diversity of reptiles and amphibians along drift fence arrays. *Herpetological Review* **34**, 39-42.

Garden J. G., Mcalpine C. A., Possingham H. P. and Jones D. N. (2007a) Habitat structure is more important than vegetation composition for local-level management of native terrestrial reptile and small mammal species living in urban remnants: A case study from Brisbane, Australia. *Austral Ecology* **32**, 669-685.

Garden J. G., McAlpine C. A., Possingham H. P. and Jones D. N. (2007b) Using multiple survey methods to detect terrestrial reptiles and mammals: what are the most successful and cost-efficient combinations? *Wildlife Research* **34**, 218-227.

Gibbon J. W., Scott D. E., Ryan T. J., Buhlmann K. A., Tuberville T. D., Metts B. S., Greene J. L., Mills T., Leiden Y. and Poppy S. (2000) The Global Decline of Reptiles, Déjà Vu Amphibians. *BioScience* **50**, 653-666.

Goldingay R. L. and Newell D. A. (2017) Small-scale field experiments provide important insights to restore the rock habitat of Australia's most endangered snake. *Restoration Ecology* **25**, 243-252.

Greenberg C. H., Neary D. G. and Harris L. D. (1994) A comparison of herpetofaunal sampling effectiveness of pitfall, single-ended, and double-ended funnel traps used with drift fences. *Journal of Herpetology* **28**, 319-324.

Hampton P. (2007) A comparison of the success of artificial cover types for capturing amphibians and reptiles. *Amphibia-Reptilia* **28**, 433-437.

Hussey B. M. J. (1998) *How to Manage your Granite Outcrops*. Department of Conservation and Land Management, Como, Western Australia.

Hutchens S. J. and DePerno, C. S. (2009) Efficacy of sampling techniques for determining species richness estimates of reptiles and amphibians. *Wildlife Biology* **15**, 113-122.

Jellinek S., Driscoll D. A. and Kirkpatrick J. B. (2004) Environmental and vegetation variables have a greater influence than habitat fragmentation in structuring lizard communities in remnant urban bushland. *Austral Ecology* **29**, 294-304.

Jellinek S., Parris K. M., McCarthy M. A., Wintle B. A. and Driscoll D. A. (2014) Reptiles in restored agricultural landscapes: the value of linear strips, patches and habitat condition. *Animal Conservation* **17**, 544–554.

Kavanagh R., Law B., Lemckert F., Stanton M., Chidel M., Brassil T, Towerton A. and Herring M. (2005) *Biodiversity in Eucalypt Plantings Established to Reduce Salinity*. Rural Industries Research and Development Corporation, Joint Venture Agroforestry Program, Canberra, ACT.

Kay G., Barton P., Driscoll D., Cunningham S., Blanchard W., McIntyre S. and Lindenmayer D. (2016) Incorporating regional-scale ecological knowledge to improve the effectiveness of large-scale conservation programmes. *Animal Conservation* **19**, 515-525.

Kay G. M., Michael D. R., Crane M., Okada S., MacGregor C., Florance D., Trengove D., McBurney L., Blair D. and Lindenmayer D. B. (2013) A list of reptiles and amphibians from Box Gum Grassy Woodlands in south-eastern Australia. *Check List* **9**, 476-481.

Lentini P. E., Fischer J., Gibbons P., Hanspach J. and Martin T. G. (2011a) Value of large-scale linear networks for bird conservation: a case study from travelling stock routes, Australia. *Agriculture, Ecosystems & Environment* **141**, 302-309.

Lentini P. E., Fischer J., Gibbons P., Lindenmayer D. B. and Martin T. G. (2011b) Australia's stock route network: 1. A review of its values and implications for future management. *Ecological Management & Restoration* **12**, 119-127.

Lettink M. and Cree A. (2007) Relative use of three types of artificial retreats by terrestrial lizards in grazed coastal shrubland, New Zealand. *Applied Herpetology* **4**, 227-243.

Lindenmayer D., Cunningham R., Tribolet C., Donnelly C. and MacGregor C. (2001) The Nanangroe landscape experiment: baseline data for mammals, reptiles and nocturnal birds. *Biological Conservation* **101**, 157-169.

Lindenmayer D., Knight E., Crane M., Montague-Drake R., Michael D. and MacGregor C. (2010a) What makes an effective restoration planting for woodland birds? *Biological Conservation* **143**, 289-301.

Lindenmayer D. and Likens G. E. (2010) *Effective Ecological Monitoring*. CSIRO Publishing. Collingwood, Melbourne.

Lindenmayer D., Wood J., Montague-Drake R., Michael D., Crane M., Okada S., MacGregor C. and Gibbons P. (2012a) Is biodiversity management effective? Cross-sectional relationships between management, bird response and vegetation attributes in an Australian agri-environment scheme. *Biological Conservation* **152**, 62-73.

Lindenmayer D. B., Cunningham R. B., Crane M., Montague-Drake R. and Michael D. (2010b) The importance of temperate woodland in travelling stock reserves for vertebrate biodiversity conservation. *Ecological Management & Restoration* **11**, 27-30.

Lindenmayer D. B., Cunningham R. B., MacGregor C., Crane M., Michael D., Fischer J., Montague-Drake R., Felton A. and Manning A. (2008) Temporal changes in vertebrates during landscape transformation: a large-scale "natural experiment". *Ecological Monographs* **78**, 567-590.

Lindenmayer D. B. and Franklin J. F. (2002) *Conserving Forest Biodiversity: A Comprehensive Multiscaled Approach*. Island Press. Covelo, California.

Lindenmayer D. B., Zammit C., Attwood S. J., Burns E., Shepherd C. L., Kay G. and Wood J. (2012b) A novel and cost-effective monitoring approach for outcomes in an Australian biodiversity conservation incentive program. *PloS one* **7**, e50872.

Manning A. D., Cunningham R. B. and Lindenmayer D. B. (2013) Bringing forward the benefits of coarse woody debris in ecosystem recovery under different levels of grazing and vegetation density. *Biological Conservation* **157**, 204-214.

McAlpine C. A., Bowen M. E., Smith G. C., Gramotnev G., Smith A. G., Cascio A. L., Goulding W. and Maron M. (2015) Reptile abundance, but not species richness, increases with regrowth age and spatial extent in fragmented agricultural landscapes of eastern Australia. *Biological Conservation* **184**, 174-18.

McDiarmid R. W. (2012) *Reptile Biodiversity: Standard Methods for Inventory and Monitoring*. University of California Press. California.

McDonald T., Jonson J. and Dixon K. W. (2016) National standards for the practice of ecological restoration in Australia. *Restoration Ecology* 24, 4-32.

McDougall A., Milner R. N., Driscoll D. A. and Smith A. L. (2016) Restoration rocks: integrating abiotic and biotic habitat restoration to conserve threatened species and reduce fire fuel load. *Biodiversity and Conservation* **25**, 1529-1542.

Michael D. R. and Alexander J. (2015) Records of the Inland Carpet Python *Morelia spilota metcalfei* (Serpentes: Pythonidae) in the North East Catchment Management Area, north-east Victoria, and the implications for fire planning. *The Victorian Naturalist* **132**, 36-43.

Michael D. and Lindenmayer D. (2010) *Reptiles of the NSW Murray Catchment: A Guide to Their Identification, Ecology and Conservation*. CSIRO Publishing. Collingwood, Melbourne.

Michael D. R. and Lindenmayer D. B. (2008) Records of the inland carpet python Morelia spilota metcalfei (Serpentes: Pythonidae) from the south-western slopes of New South Wales. *Proceedings of the Linnean Society of New South Wales* **129**, 253-261

Michael D. R. and Lindenmayer D. B. (2011) Diplodactylus tessellatus Gunther, 1875 (Squamata: Diplodactylidae), Parasuta dwyeri Greer, 2006 and Suta suta Peters, 1863 (Squamata: Elapidae): Distribution extension in the Murray catchment of New South Wales, South-eastern Australia. *CheckList* **7**, 578-80.

Michael D. R. and Lindenmayer D. B. (2012) Vegetation structure and floristics of granite landforms in the South-west Slopes of New South Wales. *Cunninghamia* **12**, 309-323.

Michael D. R., Cunningham R. B. and Lindenmayer D. B. (2008) A forgotten habitat? Granite inselbergs conserve reptile diversity in fragmented agricultural landscapes. *Journal of Applied Ecology* **45**, 1742-1752.

Michael D. R., Lunt I. D. and Robinson W. A. (2004) Enhancing fauna habitat in grazed native grasslands and woodlands: use of artificially placed log refuges by fauna. *Wildlife Research* **31**, 65-71.

Michael D., Crane M., Holliday S., Lindenmayer D., MacGregor C., McBurney L. and Montague-Drake R. (2010a) A range extension for the prong-snouted blindsnake Ramphotyphlops bituberculatus (Typholpidae) in the south-western slopes of NSW. *Herpetofauna* **37**, 81-82.

Michael D. R., Cunningham R. B. and Lindenmayer D. B. (2010b) Microhabitat relationships among five lizard species associated with granite outcrops in fragmented agricultural landscapes of south-eastern Australia. *Austral Ecology* **35**, 214-225.

Michael D. R., Cunningham R. B. and Lindenmayer D. B. (2010c) The social elite: habitat heterogeneity, complexity and quality in granite inselbergs influence patterns of aggregation in Egernia striolata (Lygosominae: Scincidae). *Austral Ecology* **35**, 862-870.

Michael D. R., Lindenmayer D. B. and Cunningham R. B. (2010d) Managing rock outcrops to improve biodiversity conservation in Australian agricultural landscapes. *Ecological Management and Restoration* **11**, 43-50.

Michael D. R., Cunningham R. B. and Lindenmayer D. B. (2011a) Regrowth and revegetation in temperate Australia presents a conservation challenge for reptile fauna in agricultural landscapes. *Biological Conservation* **144**, 407-415

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**, 149-162.

Michael D. R., Ikin K., Crane M., Okada S. and Lindenmayer D. B. (2017) Scale-dependent occupancy patterns in reptiles across topographically different landscapes. *Ecography* **40**, 415-424.

Michael D. R., Kay G. M., Crane M., Florance D., MacGregor C., Okada S., McBurney L., Blair D. and Lindenmayer D. B. (2015) Ecological niche breadth and microhabitat guild structure in temperate Australian reptiles: Implications for natural resource management in endangered grassy woodland ecosystems. *Austral Ecology* **40**, 651-660.

Michael D. R., Lindenmayer D. B., Crane M., MacGregor C., Montague-Drake R. and McBurney L. (2011b) Reptilia, Murray catchment, New South Wales, south-eastern Australia. *Check List* **7**. 25-29.

Michael D. R., Wood J. T., O'Loughlin T. and Lindenmayer D. B. (2016) Influence of land sharing and land sparing strategies on patterns of vegetation and terrestrial vertebrate richness and occurrence in Australian endangered eucalypt woodlands. *Agriculture, Ecosystems & Environment* **227**, 24-32.

Michael D. R., Wood J. T., Crane M., Montague-Drake R. and Lindenmayer D. B. (2014) How effective are agri-environment schemes for protecting and improving herpetofaunal diversity in Australian endangered woodland ecosystems? *Journal of Applied Ecology* **51**, 494-504.

Mortelliti A., Michael D. R. and Lindenmayer D. B. (2015) Contrasting effects of pine plantations on two skinks: results from a large-scale 'natural experiment' in Australia. *Animal Conservation* **18**, 433-441.

Moseby K. and Read J. (2001) Factors affecting pitfall capture rates of small ground vertebrates in arid South Australia. II. Optimum pitfall trapping effort. *Wildlife Research* **28**, 61-71.

Munro N. T., Lindenmayer D. B. and Fischer J. (2007) Faunal response to revegetation in agricultural areas of Australia: A review. *Ecological Management & Restoration* **8**, 199–207.

Norris E. H. and Thomas J. (1991) Vegetation on rocky outcrops and ranges in central and south-western New South Wales. *Cunninghamia* **2**, 411-441.

Pulsford S. A., Driscoll D. A., Barton P. S. and Lindenmayer D. B. (2017) Remnant vegetation, plantings, and fences are beneficial for reptiles in agricultural landscapes. *Journal of Applied Ecology*. doi: 10.1111/1365-2664.12923.

Ryan P. (1999) The use of revegetated areas by vertebrate fauna in Australia: A review. In: *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration* (eds R. J.Hobbs and C. J.Yates), pp. 318-335. Surrey Beatty & Sons, Chipping Norton, NSW.

Schutz A. J. and Driscoll D. A. (2008) Common reptiles unaffected by connectivity or condition in a fragmented farming landscape. *Austral Ecology* **33**, 641-652.

Thompson G. G. and Thompson S. A. (2007) Usefulness of funnel traps in catching small reptiles and mammals, with comments on the effectiveness of the alternatives. *Wildlife Research* **34**, 491-497.

Vesk P. A. and Mac Nally R. (2006) The clock is ticking - revegetation and habitat for birds and arboreal mammals in rural landscapes of southern Australia. *Agriculture, Ecosystems & Environment* **112**, 356-366.

Vesk P. A., Nolan R., Thomson J. R., Dorrough J. W. and Mac Nally R. (2008) Time lags in provision of habitat resources through revegetation. *Biological Conservation* **141**, 174-186.

Welbourne D. J., MacGregor C., Paull D. and Lindenmayer D. B. (2015) The effectiveness and cost of camera traps for surveying small reptiles and critical weight range mammals: a comparison with labour-intensive complementary methods. *Wildlife Research* **42**, 414-425.

Wilson S. and Swan G. (2013) *A Complete Guide to Reptiles of Australia* (5th edn). New Holland Publishers, Sydney.