Predicting the effect of climate change on a range-restricted lizard in southeastern Australia

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Abstract

Climate change is ranked as one of the most severe threats to global biodiversity. This global phenomenon is particularly true for reptiles whose biology and ecology are closely linked to climate. In this study, we used over 1,300 independent occurrence points and different climate change emission scenarios to evaluate the potential risk of changing climatic conditions on the current and future potential distribution of a rock-dwelling lizard; the velvet gecko. Furthermore, we investigated if the current extent of protected area networks in Australia captures the full range distribution of this species currently and in the future. Our results show that climate change projections for the year 2075 have the potential to alter the distribution of the velvet gecko in southeastern Australia. Specifically, climate change may favor the range expansion of this species to encompass more suitable habitats. The trend of range expansion was qualitatively similar across the different climate change scenarios used. Additionally, we observed that the current network of protected areas in southeast Australia does not fully account for the full range distribution of this species currently and in the future. Ongoing climate change may profoundly affect the potential range distribution of the velvet gecko population. Therefore, the restricted habitat of the velvet geckos should be the focus of intensive pre-emptive management efforts. This management prioritization should be extended to encompass the increases in suitable habitats observed in this study in order to maximize the microhabitats available for the survival of this species.

Key words: bioclimatic variables, climate change, environmental niche models, range expansion, reptiles.
For reptiles in particular, decline and extirpations of large populations have occurred in many parts of the world, and climate change is one of the leading causal agents postulated to explain these declines (Araújo et al. 2006; Sinervo et al. 2010; Clusella-Trullas et al. 2011). This is mainly because, their biology and ecology are closely tied to climate; especially changes in environmental temperature (Araújo et al. 2006; Tewksbury et al. 2008; Sinervo et al. 2010). Specifically, several populations of lizards around the globe have been significantly threatened by changing climatic conditions, and recent research has predicted significant declines over the next century (Sinervo et al. 2010). This is particularly true for tropical species, which are already living close to their physiological optimum levels (Deutsch et al. 2008). Body temperatures higher than optimum creates physiological stress, reduced performance, and increased disease susceptibility; ultimately leading to population declines and extinction (Root et al. 2003; Sinervo et al. 2010; Huey et al. 2012). For example, projected temperature increases of between 1.1 °C and 6.4 °C by the year 2100 would increase the metabolic rates of ectotherms by 10–75% (Bickford et al. 2010). A rise in metabolic rates coupled with reduced foraging time could negatively affect reproduction and subsequently population growth rates (Bickford et al. 2010; Logan et al. 2014). However, the vulnerability of a species depends on its sensitivity to environmental change, its exposure to that change, its resilience or ability to recover, and its potential to adapt to these changes (Williams et al. 2008). Ideally, to predict species at risk from global warming and climate change, we need information about their habitat selection and colonization ability. For example, species with lower dispersal ability may face difficulties to colonize suitable habitats due to specialized habitat requirements (Hughes 2000, 2003; Araújo et al. 2006; Huey et al. 2012). Therefore, investigating how reptiles, especially the range-restricted ones, will respond to a new climatic regime is critical if we are to mitigate the impacts of climate change from a conservation point of view.

Lately, researchers have developed tools that enable the evaluation of the potential geographic distribution of a species’ abiotic niche from changing climatic conditions. Of the many different tools available, species ecological niche models (ENMs) have been widely used (Cabrelli and Hughes 2015, Melville et al. 2016; Tingley et al. 2016). These models relate data on species’ occurrence (i.e., presence/absence) to the bioclimatic conditions of a given area, therefore allowing us to determine the potential climate envelope of a species. In so doing, geographic areas that fall within or outside of the current range distribution of the species could be identified (Thuiller et al. 2005). Such approaches have found major applications in biological conservation science. For example, mapping where rare and endangered species are most likely to occur in the landscape, species discovery; prioritizing conservation sites; and identifying potential restoration sites, especially after invasion amongst others (Williams et al. 2009). In constructing climate envelopes for conservation purposes, some challenges have emerged especially for range-restricted rock-dwelling lizards such as the velvet gecko Amalosia lesueurii (our study species) in southeastern Australia. Among others, the species occurrence data and the spatial resolution at which bioclimatic or microclimatic data are downscaled have increasingly been cited in the scientific literatures (see also Wisé et al. 2008; Rebaudo et al. 2016; and references therein). To contribute to the growing body of knowledge on this topic, we used a range-restricted species A. lesueurii, to evaluate the effect of current and future climate change on the range distribution in southeastern Australia, employing an ENM approach. Additionally, we investigate if the current extent of protected area networks in Australia captures the full range distribution of this species currently and in the future.

Materials and Methods
Species’ occurrence data
A total of 1,320 independent occurrences for A. lesueurii were collected from the Atlas of Living Australia (www.ala.org.au). These occurrence data were supplemented with our survey data collected between September 2013 and November 2015.

Climatic data
Spatially continuous current and future climate data were downloaded from the WorldClim database (www.worldclim.org; Hijmans et al. 2005). The current data represented interpolation of average monthly climatic records obtained from weather stations between 1950 and 2000, while projected future climate for the year 2075 was estimated using the Commonwealth Scientific and Industrial Research Organization (CSIRO-MK3.0) general circulation models (GCM) at 2.5 arcmin resolution. Although the spatial resolution of WorldClim dataset used to infer the thermal niche of small ectotherms affects the final model outputs (Hannah et al. 2014 and references therein), this topic is still highly debatable in scientific literatures (see Bennie et al. 2014; Hannah et al. 2014; Storlie et al. 2014; Rebaudo et al. 2016). In this study, we used the WorldClim datasets following the same line of thought as Rebaudo et al. (2016) and included all 19 bioclimatic variables as potential predictors (see Supplementary Table S1). For future climate projections, we considered 3 representative concentration pathways (RCPs) or emission scenarios, to account for differences across climate scenarios. For the current study, we choose 3 scenarios representing different magnitudes of greenhouse gas emissions: a high RCP 6.0 characterized by a rising radiative forcing pathway leading to ~1370 ppm CO₂ with a global mean temperature rise of 2.2 °C; a medium RCP 4.5 where greenhouse gas emissions stabilizes at ~650 ppm CO₂ with a global mean temperature rise of 1.8 °C; and lastly, the lowest RCP3PD 3.0 where greenhouse gas emissions peak at ~490 ppm CO₂ with a global mean temperature rise of 1.0 °C by 2100 (Riahi et al. 2011; Thomson et al. 2011; van Vuuren et al. 2011). For convenience, in this study we refer to these RCPs as “low mitigation” (RCP3PD), “medium mitigation” (RCP4.5), and “high mitigation” (RCP6.0).

Evaluation of suitable habitat for A. lesueurii
We applied an ENM approach that relies on presence of species and background data to generate correlative models for both current and future habitat suitability for A. lesueurii species. We used MaxEnt version 3.3.3 (Phillips et al. 2006) as it outperforms similar modeling algorithms [but see also Elith et al. (2006) for some of its numerous advantages]. We used 70% of our occurrence data for model training while withholding the remaining 30% for model evaluation. Although we lacked actual absence data for this study species, background or pseudo-absence data was generated assuming 1.5 times the number of presence points, which characterizes the environmental conditions of the study area (Phillips et al. 2009; Bezeng et al. 2017). Model performance was evaluated using the area under the curve (AUC) statistics. We then ran 15 subsampling replicates employing 5,000 iterations for each model. These replicates and iterations were considered sufficient for model convergence. Finally, to reduce model extrapolation errors caused by
non-analogous climatic conditions (see Fitzpatrick and Hargrove 2009), we used a multivariate environmental similarity surface (MESS) analysis to restrict model projections to analogous environments where true presence and background records were sampled (see also Elith et al. 2010).

ENM outputs followed a logistic distribution, ranging from 0 (climatically unsuitable areas) to 1 (climatically suitable areas). For all model runs, we quantified the difference in geographical range extent of projected distributions between current and future climate scenarios, in which the extent of potential ranges could be determined by negative values (indicating a net reduction in climatically suitable areas with climate change) or positive values (indicating a net expansion of climatically suitable areas with climate change). We explored potential bioclimatic variables that might be driving range change for our study species by running a regression of change in predicted climate suitability against change in each bioclimatic variable, in turn.

Protected area data
To evaluate if the current extent of protected areas in Australia captures the full range distribution of this gecko species under climate change, we overlaid the current and future potential range distribution with a shapefile of currently protected area network in Australia downloaded from the Collaborative Australian Protected Areas Database (CAPAD 2014). This database provides spatial information about government, indigenous, private and jointly managed protected areas for the Australian continent and also meets the criteria for defining protected areas according to the IUCN standards. This analysis was performed using ArcGIS version 10.3 software.

Results
Model performances across all the species’ ENMs using MaxEnt were high (AUC > 0.995 ± 0.014). Under current climatic conditions, areas that are climatically suitable for the range-restricted velvet gecko are coastal regions and ranges of New South Wales and far southeastern Queensland, which matches the areas where field observations were carried out (Figure 1).

Our results from models projected into the future, shows that climate change projections for the year 2075 have the potential to alter the distribution of the velvet gecko in southeastern Australia. Specifically, climate change may favor the range expansion of this species to encompass more suitable habitats (Figure 2, but see also Supplementary Figures S1 and S2 for alternative RCPs). Under the “low mitigation” (i.e., RCP3PD), the potential area of range expansion was ~726 x 10³ km². This trend was qualitatively consistent across the different climate change scenarios, and we observed no significant difference when alternative RCPs were used (see Table 1; P > 0.05).
From the regression analysis, we found that similar temperature and precipitation bioclimatic variables were important in driving range change for *A. lesueurii* in southeast Australia. Particularly, we found that minimum temperature of coldest month, annual precipitation, precipitation of wettest month, precipitation of driest month, precipitation of wettest quarter, precipitation of driest quarter, and precipitation of warmest quarter (see Supplementary Table S2 for correlation coefficients) were important in driving range change. Lastly, we evaluated the area of overlap between the current protected area network and the range shift of the velvet gecko in order to determine if the current extent of protected areas in southeast Australia accounts for the range expansion of this species.

Surprisingly, we found that the current network of protected areas in southeast Australia does not fully account for the full range distribution of this species currently and in the future. For example, we found that, of the 2,009 protected areas that overlapped with the current distribution of this species, a significant number (i.e., 103) were outside the species’ current range distribution. Likewise, of the 2,099 protected areas that overlapped with the future distribution of this species, 118 of them were outside the species’ future range distribution, representing ~30% of the species’ future range area (see Figure 3A and B).

**Discussion**

The recent report from the Intergovernmental Panel on Climate Change (IPCC) predicts that human activities are driving global climate change, which is likely to further increase in the future (IPCC, 2014). Thus, many species are expected to shift their current distribution to track future climate change. For example, there are growing evidences documenting the movement of species northward and upward in elevation (Parmesan 2006; Kelly and Goulden 2008; Lenoir et al. 2008; Moritz et al. 2008). In the past, many studies have attempted to model the potential current and future distribution of range-restricted species using an environmental niche modeling approach (Williams et al. 2009; Cabrelli and Hughes 2015; Melville et al. 2016). However, using ENM for range-restricted or specialized habitat species is particularly challenging. First, the

**Table 1.** Projected impacts of climate change by 2075 in terms of changes in range size for the velvet gecko in southeastern Australia across 3 climate change scenarios

<table>
<thead>
<tr>
<th>Low mitigation</th>
<th>Medium mitigation</th>
<th>High mitigation</th>
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<tbody>
<tr>
<td>Current</td>
<td>Future</td>
<td>PARC</td>
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<tr>
<td>Current</td>
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<tr>
<td>Current</td>
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<tr>
<td>7,781</td>
<td>8,507</td>
<td>726</td>
</tr>
<tr>
<td>7,781</td>
<td>8,510</td>
<td>729</td>
</tr>
<tr>
<td>7,781</td>
<td>8,388</td>
<td>607</td>
</tr>
</tbody>
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PARC, potential area of range change ($\times 10^3$ km$^2$).

**Figure 2.** Change in potential species distribution between current and projected climate for the year 2075 employing the “low mitigation” (i.e., RCP3PD) emission scenario. Red color indicates areas that are climatically suitable for species occurrence while green color indicates areas that are climatically unsuitable for species occurrence.
narrow distribution and sample sizes for such species come with an additional challenge for model robustness from a statistical point of view (Stockwell and Peterson 2002; Pearson et al. 2007; Wisz et al. 2008). Second, the occurrence data for range-restricted species are often sporadic, adding more bias to modeling their potential distribution. Therefore, defining their full extent becomes less reliable from a management perspective as opposed to understanding their habitat occupancy (Williams et al. 2009). Consequently, data consideration for range-restricted species imposes a huge challenge for ENMs because they are meant to identify the full extent of a species’ potential distribution but may underestimate this range if data are sporadic or intermittent (McPherson and Jetz 2007).

In this study, we used an environmental niche modeling approach as implemented in the MaxEnt algorithm since this method is especially good in handling species with few occurrences (Elith et al. 2006; Phillips et al. 2006; Wisz et al. 2008) together with future climate projections, to evaluate how changing climatic conditions will affect the potential distribution of a range-restricted lizard species in southeast Australia. Our results demonstrate that climate change projections for the year 2075 have the potential to alter the distribution of the velvet gecko in southeastern Australia. Specifically, climate change may favor the range expansion of this species to encompass more suitable habitats. However, the magnitude of the effects of warming on the velvet gecko and on reptiles in general will depend on physiological and/or behavioural plasticity or evolutionary adaptations of different species (Williams et al. 2008; Chevin et al. 2010; Hoffmann 2010; Hoffmann et al. 2013; Monasterio et al. 2013). Therefore, as a potential source of resilience, ectotherms like the velvet gecko have in situ capabilities to deal with extreme climates (see also Sunday et al. 2014). For example, this species inhabits closed systems (i.e., loose surface rocks), but in most rocky flat forms there are few loose surface rocks for animals to settle under. As a result, adult lizards may experience higher temperature during the summer. Additionally, over the last 25 years, female velvet geckos at our study sites near Nowra have continuously used the same communal nest sites for oviposition, suggesting rather limited plasticity in their choice of nest sites. Therefore, as a survival strategy, this species must leave these sites but employing this strategy is not possible. Thus, to prevent overheating, the geckos will need to move between hotter and cooler surfaces more often, potentially exposing them to avian predators and lowering their chances of survival. Notwithstanding, projecting future distributions under 3 RCPs, we identified suitable climate refugia where this species is likely to occupy. This includes southeastern New South Wales particularly toward the Australian Capital Territory. We found that similar temperature and precipitation bioclimatic variables were important in driving range change for A. lesueurii in southeast Australia. Additionally, we revealed some mismatches in the potential area of overlap in the range distribution of this gecko species currently and in the future with the network of protected areas in southeastern Australia.

Although our results show qualitatively a similar range expansion across the different climate change scenarios for this species, we caution that results from environmental niche models should be interpreted with some precaution. This is especially true for species with narrow geographical distributions or specialized habitat requirements like the velvet gecko and the quality of data use for characterizing their climate envelopes (see also Wisz et al. 2008;
Rebaudo et al. 2016). However, ENMs work on the assumption that a species is at equilibrium with its environment (i.e., a species is present in all suitable habitats and absent from all unsuitable habitats (Guisan and Thuiller 2005). Notwithstanding, the climatic niche at equilibrium of a species is limited by both the small-scale abiotic and biotic interactions (e.g., competition, predation, pathogens, dispersal limitations), which are rarely incorporated in ENMs (Le Maître et al. 2008; Guisan et al. 2014). Additionally, major weaknesses have been observed using WorldClim data to infer the thermal niche for small ectotherms (see Hannah et al. 2014 and references therein). However, this topic is still highly debatable in scientific literatures as there are protagonists (Hannah et al. 2014; Storlie et al. 2014) as well as antagonists (Bennie et al. 2014). In a recent analysis by Rebaudo et al. (2016), they used 3 different climatic datasets at different spatial scales (i.e., WorldClim, weather station, and microclimatic) to calibrate species ENMs. They showed that models calibrated with microclimatic dataset predicted the observed abundance of the study species but was however less accurate than the WorldClim datasets when performed at a coarse scale. Therefore, in the absence of microclimatic datasets, WorldClim datasets are well suited for calibrating the thermal niche of small ectotherms, given that, the availability of microclimatic data sets still represents a major challenge to overcome (Rebaudo et al. 2016). Nevertheless, we used WorldClim data to calibrate the thermal niche of the velvet gecko, but we further stress the point that ENMs provide only a probabilistic framework for a species’ potential distributions, which needs to be verified using empirical data on many factors acting in a synergetic manner to determine the realized niche of a species.

Implications for the management of *A. lesueurii*

The velvet gecko is a nocturnal lizard (Cogger 2000), which relies on sandstone rocks for shelter sites, and this habitat is threatened by the illegal removal of “bush rocks” (Shine et al. 1998). For example, in Dharawal National Park and Morton National Park, the velvet gecko’s habitats (i.e., rock platforms) are not connected to each other but rather separated by a minimum distance of approximately 2–3 km (Webb et al. 2008; Pike et al. 2010). Therefore, it is highly unlikely that they would shift rocky platforms due to higher temperatures, although shifting habitats (suitable microhabitats) or finding suitable retreat sites represent possible survival mechanisms to avoid lethally high temperatures in the future. In addition, the endangered broad-headed snake *Hoplocephalus bungaroides* is a major prey of this gecko species and its viability is critical for the persistence of broad-headed snakes (Pikes et al. 2010).

Therefore, the relative rarity of *A. lesueurii*, together with its range-restricted nature and absence of population data, presents a daunting scenario for its conservation. Furthermore, human activities through the illegal removal of “bush rocks” and constant disturbance by reptile collectors provide a further threat to this species’ survival. This phenomenon is further compounded by increases in air temperatures, which in turn increase their nest temperatures. Thus, the hatchlings survival is significantly affected which might lead to a higher probability of extinction (Dayananda et al. 2016). If the frequency and duration of summer heat waves increases in the future, coupled with anthropogenic habitat destruction, this may have profound effects on the velvet gecko population. In turn, local extinctions of geckos will have negative consequences for an endangered predator (broad-headed snake) that feeds almost entirely on velvet geckos. These findings have important implications for conservation of both predators and prey. We therefore suggest that the restricted habitat of the velvet gecko currently as predicted by climate should be a focus of intensive pre-emptive management in order to conserve this species from extinction. These results are consistent with previous studies, and in some cases management initiatives are already in place to restore the habitat of this species (see Croak et al. 2010; 2013). For example, artificial refugia have been constructed to allow crevices where this species can hide from lethal temperatures (Croak et al. 2010). These artificial rocks help to increase the colonization of both adults and juvenile geckos and we suggest that the addition of these artificial refugia should be continued in an effort to conserve this species. This is especially evident in the Dharawal National Park (67 km south of Sydney) and Morton National Park (160 km south of Sydney), which were important habitats for the velvet gecko but heavily degraded by bush-rock collection. Additionally, we show that the current network of protected areas in southeast Australia does not fully account for the full range distribution of this species currently and in the future. Therefore, present conservation actions to protect this species from anthropogenic activities should be increased to encompass the slight increases in suitable habitats of this endemic species in southeastern Australia as shown by this study. All these opportunities should be seized as they represent important conservation measures to protect this range-restricted species from anthropogenic activities.

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**Supplementary material**

Supplementary material can be found at https://academic.oup.com/cz.

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