Distributional limits of Eastern Blue-tongue Lizards *Tiliqua scincoides,* Blotched Blue-tongue Lizards *T. nigrolutea* and Shingleback Lizards *T. rugosa* (Gray) in New South Wales

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ABSTRACT

Climate profiles generated by BIOCLIM6 for three species of lizards in the genus *Tiliqua* (*T. scincoides, T. nigrolutea* and *T. rugosa*), within New South Wales. Predicted distributions produced from these profiles were similar to previously published distributions for each species. *Tiliqua scincoides* and *T. rugosa* are almost equal in their temperature requirements which are higher than those for *T. nigrolutea.* Higher precipitation defines the distribution of both *T. scincoides* and *T. nigrolutea* with the latter having the higher minimum precipitation values. *Tiliqua rugosa* appears restricted by the association of maximum temperature and precipitation and minimum temperature during cooler months. *Tiliqua nigrolutea* is limited by minimum precipitation to areas of higher elevation where summers and winters are comparatively cooler and appears the most temperature-sensitive species. *Tiliqua scincoides* appears restricted by minimum precipitation and minimum temperature but inhabits the widest range of environments from the east coast to central New South Wales. *Tiliqua scinoides* has the widest range of values for climatic parameters, suggesting that it is the least sensitive to climatic factors.

INTRODUCTION

The Eastern Blue-tongue *Tiliqua scincoides,* the Blotched Blue-tongue *T. nigrolutea* and the Shingleback *T. (Trachydosaurus) rugosa* are diurnal ground-dwelling lizards, attaining maximum snout-vent length of approximately 350–370 mm (Shea 1992). Although these species have a similar diet and similar daily habits, each has a different distribution with a variety of habitats throughout their individual distributions (Cogger 1992). *Tiliqua scincoides* inhabits southeastern South Australia through Victoria, eastern New South Wales and most of Queensland, with an isolate distribution in central Australia (Johnston 1992). *Tiliqua nigrolutea* has the most limited distribution of the three species, occurring in southeastern South Australia through southern Victoria to the highlands of southern and central New South Wales, eastern and northern Tasmania and the islands of Bass Strait (Cogger 1992). *Tiliqua rugosa* is distributed through the semi-arid areas of southern and eastern Australia, being absent from the coast and ranges of the east and south-east.

BIOCLIM6, a bioclimatic analysis and prediction system (Busby 1991), is a useful tool for evaluating distributions of animals and plants and offers substantial advantages for biological surveying. The BIOCLIM6 system produces a climate profile for a taxon from known capture localities. From this information, predicted distributions of particular species may be mapped (Busby 1991). We used BIOCLIM6 to characterize climate profiles for *T. scincoides, T. nigrolutea* and *T. rugosa* and then to predict distribution ranges on the basis of the climate profiles, with the aim of interpreting the limiting factors to distribution.

By making an intrageneric comparison of three morphologically and ecologically similar species, we used BIOCLIM6 to address the question, "what factors influence their different distributions?" *A priori,* we predicted that ambient temperature would be a major climatic factor involved in influencing the distribution of *T. scincoides, T. nigrolutea* and *T. rugosa* because, as ectotherms, they are dependent upon environmental temperatures for daily activity. From previously published distributions of these species (Cogger 1992), we predicted that *T. nigrolutea* would be the most temperature sensitive due to its cool temperate distribution, while *T. scincoides* and *T. rugosa* would be less temperature sensitive due respectively to their warm temperate and warm arid distributions.

METHODS

The BIOCLIM6 programme developed by NSW National Parks and Wildlife Service was used to analyse distributions of three species of *Tiliqua.* This system incorporates elevation and was developed for use in New South Wales and northern Victoria.

Capture localities for *T. scincoides, T. nigrolutea* and *T. rugosa* were obtained from records of Australian museums. The latitude and longitude were determined for each locality using Reader's Digest Atlas of Australia 1:100 000 maps.

Table 1. Climate profile for *Tiliqua scincoides* within New South Wales (n = 201, all temperatures in °C, all precipitation quantities in mm).

Climate Parameter	Minimum	5%	95%	Maximum
1. Annual mean temperature	11.0	11.8	18.7	20.3
2. Minimum temperature coolest month	−1.2*	−0.6	6.8	7.7
3. Maximum temperature warmest month	23.0	24.5	33.9	35.9
4. Annual temperature range (max.–min.)	16.5	19.5	30.8	31.7
5. Mean temperature coolest quarter	5.1	5.9	12.7	14.7
6. Mean temperature warmest quarter	16.7	17.9	25.9	27.7
7. Mean temperature wettest quarter	6.5	8.8	25.9	27.3
8. Mean temperature driest quarter	5.9*	8.7	20.0	24.3
9. Annual mean precipitation	281.0	378.0	1 294.0	2 031.0*
10. Precipitation wettest month	33.0	39.0	169.0	284.0
11. Precipitation driest month	15.0*	25.0	67.0	77.0
12. Coeff. variation monthly precipitation	7.7	10.6	35.3	50.6
13. Precipitation wettest quarter	92.0	107.0	474.0	814.0
14. Precipitation driest quarter	49.0*	79.0	224.0	280.0
15. Precipitation coolest quarter	56.0*	89.0	292.0	545.0*
16. Precipitation warmest quarter	71.0	94.0	433.0	729.0*

*Significant difference (>30%) between the minimum and the five percentile values or the 95 percentile and maximum values.

Table 2. Climate profile for *Tiliqua nigrolutea* within New South Wales (n = 90, all temperatures in °C, all precipitation quantities in mm).

Climate Parameter	Minimum	5%	95%	Maximum
1. Annual mean temperature	6.0*	8.9	14.8	25.4*
2. Minimum temperature coolest month	−3.2	−2.5	5.4	5.4
3. Maximum temperature warmest month	18.5	21.5	28.7	31.1
4. Annual temperature range (max.–min.)	18.5	20.2	27.6	29.8
5. Mean temperature coolest quarter	0.3**	3.0	9.7	10.9
6. Mean temperature warmest quarter	11.9	14.7	20.9	21.9
7. Mean temperature wettest quarter	0.7**	4.7	19.7	21.2
8. Mean temperature driest quarter	4.7*	5.0	19.6	21.6
9. Annual mean precipitation	599.0	663.0	1 446.0	1 883.0
10. Precipitation wettest month	65.0	69.0	171.0	204.0
11. Precipitation driest month	29.0	36.0	77.0	106.0
12. Coeff. variation monthly precipitation	8.7	9.0	35.2	41.7
13. Precipitation wettest quarter	178.0	194.0	480.0	592.0
14. Precipitation driest quarter	99.0	117.0	256.0	331.0
15. Precipitation coolest quarter	124.0	144.0	480.0	559.0
16. Precipitation warmest quarter	99.0	118.0	336.0	373.0

*Significant difference (>30%) between the minimum and the five percentile values or the 95 percentile and maximum values. **Difference >80%

Table 3. Climate profile for *Tiliqua rugosa* within New South Wales (n = 196, all temperatures in °C, all precipitation quantities in mm).

Climate Parameter	Minimum	5%	95%	Maximum
1. Annual mean temperature	11.0	12.7	20.1	20.7
2. Minimum temperature coolest month	−0.2**	0.7	5.0	5.5
3. Maximum temperature warmest month	24.6	25.9	35.5	37.0
4. Annual temperature range (max.–min.)	19.1	23.0	31.7	31.8
5. Mean temperature coolest quarter	5.9	6.7	12.0	12.4
6. Mean temperature warmest quarter	16.6	18.2	27.5	28.6
7. Mean temperature wettest quarter	5.9	7.8	27.2	28.0
8. Mean temperature driest quarter	10.5	11.3	23.1	24.8
9. Annual mean precipitation	154.0	217.0	757.0	955.0
10. Precipitation wettest month	20.0	22.0	79.0	112.0
11. Precipitation driest month	7.0*	13.0	46.0	59.0
12. Coeff. variation monthly precipitation	7.1	9.5	33.1	40.2
13. Precipitation wettest quarter	.51.0	62.0	230.0	323.0
14. Precipitation driest quarter	26.0*	47.0	146.0	182.0
15. Precipitation coolest quarter	31.0*	50.0	223.0	323.0*
16. Precipitation warmest quarter	51.0	58.0	177.5	239.0

*Significant difference (>30%) between the minimum and the five percentile values or the 95 percentile and maximum values. **Difference >80%

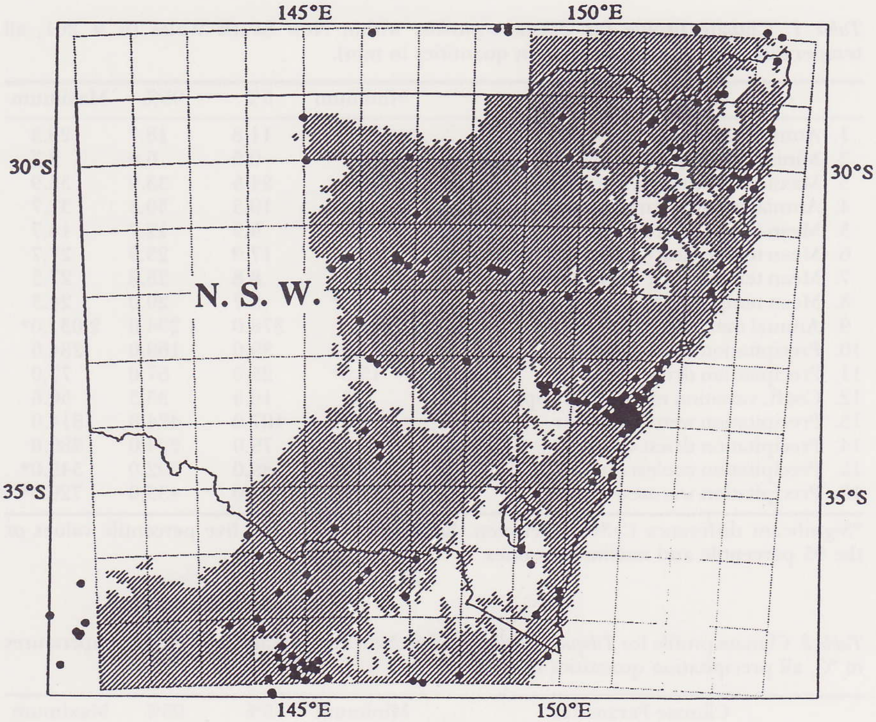

Figure 1. Capture localities (●) for *Tiliqua scincoides* and the distributions predicted by BIOCLIM6 (////) within New South Wales (Scale 1:10 000 000).

Climate profiles generated by BIOCLIM6 are based on 16 climatic parameters derived from the temperature and precipitation data (Tables 1–3), to characterize annual, seasonal and extreme components of the climatic environment (Busby 1991). The climate profiles represent a measure of monthly temperature and precipitation estimates within 0.1° latitude-longitude grids of New South Wales. BIOCLIM6 bases the predicted distribution of a species on the similarity of the climate in 0.1° grids where the species is known, to the climate of all the 0.1° grids within New South Wales. Climate profiles summarise the climatic range experienced by a species and are a collation of the climate data from capture localities of that species.

Specific differences and the representative accuracy of the climate profiles for *T. scincoides, T. nigrolutea* and *T. rugosa* were estimated by comparing minimum and maximum values to the five and 95 percentile values respectively. Values were considered significant if the difference between the minimum and five percentile, or the 95 percentile and the maximum values were greater than 30% (Tables 1–3).

RESULTS

Climate profiles

Only two temperature parameters are significant for *T. scincoides* (Table 1). For *T. nigrolutea*, the minimum and maximum values for "annual mean temperature" both differ significantly from their respective percentile values, with the minimum values for "mean temperature coolest quarter" and "mean temperature wettest quarter" for *T. nigrolutea* differing by more than 85% (Table 2). The only significant temperature parameter for *T. rugosa* is the minimum value for "minimum temperature coolest month", which differs by 82% (Table 3).

Temperature values for *T. scincoides* and *T. rugosa* are very similar with only the "minimum temperature coolest month" and "mean temperature driest quarter" being significantly lower for *T. scincoides* (Tables 1 and 3). *Tiliqua nigrolutea* has the lowest temperature values, while *T. scincoides* and *T. rugosa* have temperature parameters significantly greater than *T. nigrolutea* (Tables 1–3).

All precipitation parameters for *T. scincoides* are significant at the minimum and/or the maximum values (Table 1). In contrast, no precipitation parameters are significant for *T. nigrolutea* (Table 2). *Tiliqua rugosa* has three significant precipitation parameters (Table 3).

Precipitation values distinguish further differences between the three species. *Tiliqua rugosa* has the lowest minimum and maximum precipitation values, being lower than *T. nigrolutea* in all parameters other than "coefficient variation monthly precipitation" (Tables 2 and 3). *Tiliqua rugosa* is also lower than *T. scincoides* in all parameters except for "coefficient variation

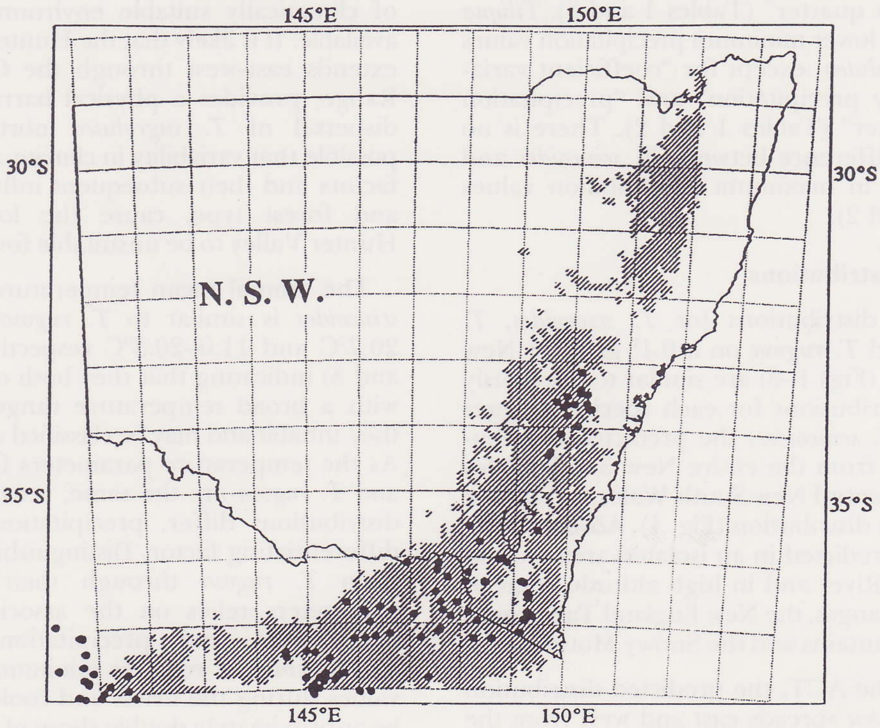

Figure 2. Capture localities (●) for *Tiliqua nigrolutea* and the distribution predicted by BIOCLIM6 (////) within New South Wales (Scale 1:10 000 000).

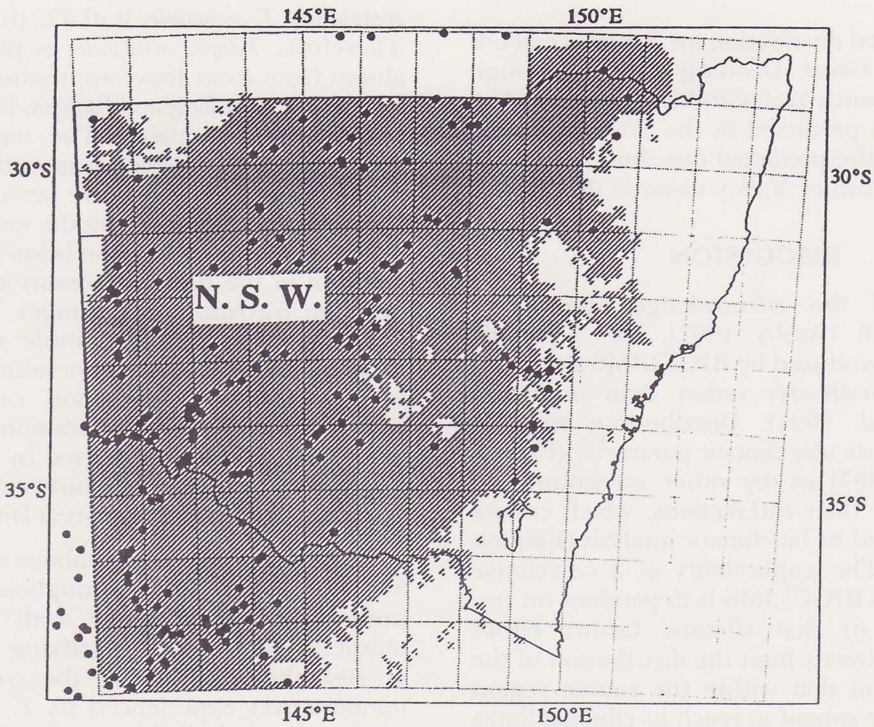

Figure 3. Capture localities (●) for *Tiliqua rugosa* and the distributions predicted by BIOCLIM6 (////) within New South Wales (Scale 1:10 000 000).

monthly precipitation" and "maximum precipitation coolest quarter" (Tables 1 and 3). *Tiliqua scincoides* has lower minimum precipitation values than *T. nigrolutea*, except for "coefficient variation monthly precipitation" and "precipitation coolest quarter" (Tables 1 and 2). There is no significant difference between *T. scincoides* and *T. nigrolutea* in maximum precipitation values (Tables 1 and 2).

Predicted distributions

Predicted distributions for *T. scincoides, T. nigrolutea* and *T. rugosa* on a 0.1° grid for New South Wales (Figs 1–3) are similar to previously published istributions for each species (Cogger 1992). For *T. scincoides*, the predicted distribution extends from the entire New South Wales coastline to central New South Wales, as far west as the known distribution (Fig. 1). Absence of *T. scincoides* is predicted in an isolated area around the Lachlan River and in high altitude areas of the Border Ranges, the New England Tablelands, the Blue Mountains and the Snowy Mountains.

North of the ACT, the predicted distribution for *T. nigrolutea* spreads east and west from the capture localities and extends north along the Great Dividing Range to the Queensland border, approximately 1 000 km further than the capture localities. Absence is predicted in the Hunter Valley while south of the Blue Mountains the predicted distribution reaches close to the coast from where it extends west to central Victoria (Fig. 2).

The predicted distribution for *T. rugosa* extends west of the Great Dividing Range through central New South Wales and into Victoria (Fig. 3). Absence is predicted in the Warrumbungle Ranges while the predicted distribution extends through the Hunter Valley towards the coast.

DISCUSSION

Because of the acknowledged limitations of BIOCLIM6 (Busby 1991), the predicted distributions produced by BIOCLIM6 should be regarded as indicative rather than predictive (Bennett *et al.* 1991). Distributions may be limited by a particular climatic parameter (Panetta and Dodd 1987) or by other environmental factors and/or their interactions, which cannot yet be predicted by bioclimatic analysis (Bennett *et al.* 1991). The applicability of a correlative model such as BIOCLIM6 is dependent on two assumptions, (i) that climatic factors either directly or indirectly limit the distribution of the species, and (ii) that within the source region the species has spread to reach its climatic limits (Panetta and Mitchell 1991).

Tiliqua nigrolutea has a predicted distribution that extends far beyond the capture localities and is potentially not inhabiting the extent of climatically suitable environments that are available. It is likely that the Hunter Valley, which extends east-west through the Great Dividing Range, provides a physical barrier preventing dispersal of *T. nigrolutea* northwards. It is possible that variability in climate, and/or physical factors and their subsequent influence on food and forest type, cause the lower elevation Hunter Valley to be unsuitable for *T. nigrolutea*.

The annual mean temperature range for *T. scincoides* is similar to *T. rugosa*, being 11.0–20.7°C and 11.0–20.3°C respectively (Tables 1 and 3) indicating that they both cope efficiently with a broad temperature range in the areas they inhabit and may be classified as eurythermic. As the temperature parameters for *T. scincoides* and *T. rugosa* are the same, yet their predicted distributions differ, precipitation may be the differentiating factor. Distinguishing *T. scincoides* from *T. rugosa* through their precipitation parameters relies on the association of both temperature and precipitation parameters. *Tiliqua scincoides* requires minimum precipitation values during the driest and coolest quarters to be approximately double those of *T. rugosa*. The need of *T. scincoides* for specific levels of minimum precipitation probably is the restriction that prevents the distribution of this species from extending into western New South Wales.

Both *T. scincoides* and *T. rugosa* are restricted by a lower tolerance to cool conditions during the winter months. The mean minimum temperature restricting *T. scincoides* is -0.6°C (five percentile). Therefore, *Tiliqua scincoides* is predicted to be absent from areas above approximately 1 000 m, such as the New England Ranges, Blue Mountains and Snowy Mountains. The mean minimum temperature of the coolest month restricting *T. rugosa* is less than 0.7°C (five percentile). Hence, *T. rugosa* is restricted along the western slopes of the Great Dividing Range to below approximately 1 000 m in the Blue Mountains and below 500 m in the Warrumbungle Ranges. The northerly decrease in restricting altitude may relate to increase in ambient temperatures associated with increased precipitation causing higher humidity levels. The association of humidity with distribution is supported by the failure of *T. rugosa* to exploit the Hunter Valley to gain access to the slopes of the Great Dividing Range.

Tiliqua nigrolutea occurs above approximately 500 m to over 2 000 m throughout its predicted range, coping efficiently with its narrower temperature range, classifying this species as stenothermic. During the wetter periods, temperatures experienced by *T. nigrolutea* are approximately half those of *T. scincoides* and *T. rugosa*. As the maximum precipitation values for *T. scincoides* and *T. nigrolutea* are not significantly different, the minimum values must differentiate the two species. Minimum precipitation values for *T. nigrolutea* are approximately double those for *T. scincoides* restricting *T. nigrolutea* to areas of greater rainfall, such as montane regions.

The morphological and ecological similarity among the species of *Tiliqua* in our analysis suggests that physiological differences are important in defining their different distributions. If thermal biology does influence distribution through physiology, species-specific differences in physiological parameters relating the characteristic temperature profile of each species distribution, should be detectable in the laboratory. The derived bioclimatic indices generated by BIOCLIM6 provide gross approximations of total energy and water inputs by providing an index of conditions during various seasons to which a particular species is subjected (Nix 1986). However, there is always a compromise between physiology and ecology, where the operational efficiency of physiological processes must remain within an adequate functional range.

ACKNOWLEDGEMENTS

This paper originated from a Bachelor of Science (Honours) project, supervised by Dr M. B. Thompson (Biological Sciences, University of Sydney) and Dr Glenn Shea (Veterinary Anatomy, University of Sydney). Support came from an Australian Research Council small grant to Dr M. B. Thompson. Thanks are extended to Murray Ellis and Anthony Ferguson of NSW National Parks and Wildlife Service for use of the BIOCLIM6 programme.

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Letter to the Editor

The Editor,
Australian Zoologist
26th March 1997

Dear Editor,

Several recent events have highlighted the damage done to Australian native fauna by exotic predators, particularly foxes and cats. These include the spectacular increases in numbers of Brush-tailed Bettongs *(Bettongia penicillata)* and Numbats *(Myrmecobius fasciatus)* in the south-west of Western Australia consequent upon an intensive fox baiting programme, the successful reintroduction of captive-bred Eastern Barred Bandicoots *(Perameles gunnii)* into fenced areas together with baiting/shooting in Victoria, and John Walmsley's activities using similar techniques in South Australia.

The fact that Long-nosed Bandicoots *(P. nasuta)* still survive on North Head in Sydney Harbour National Park while virtually all other urban populations have disappeared, suggests that the North Head bandicoots are protected in some way. This is probably because North Head is a peninsula protected (at least for the moment) by St. Patrick's Estate which forms an effective buffer between surburban Manly and the National Park.

I suggest that the Society could promote similar reintroduction programmes with some of our own endangered species in New South Wales. Suitable species will depend on the location of selected sites for enclosures (with or without baiting programmes in addition). Sites should ideally be isolated from human habitation and be on a peninsula or similar geographic feature that can be made secure with the minimum of predator-proof fencing.

Ian Hume
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