Karoo BioGaps report: Scorpion occupancy models

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Contents

1 Summary

The scorpion team, led by Lorenzo Perdini, carried out three sampling field trips in February 2017, December 2017 and February 2018, respectively. In total the team managed to visit the 30 essential pentads. Using a double-observer protocol they completed 110 transects in which they recorded 25 species from three families (*Buthidae*, *Hormuridae* and *Scorpionidae*). See Appendix A for a full list of species recorded in the surveys. Excitingly, the team captured a specimen from the Opistophthalmus genus which, as of yet, remains undescribed. The team used a combination of diurnal active searching (rock-flipping, burrow-excavating) and nocturnal search surveys.

Species were modelled as a random effect in the analysis which meant we were able to determine occupancy and detection probabilities for both individual species and the larger scorpion community as a whole. Mean community-level occupancy probability was fairly low ($\psi = 0.1$) while mean detection probability was moderate ($p = 0.5$). It was clear that there was substantial variation in these occupancy and detection probability estimates between species ($\psi_{SD} = 0.8$ and $p_{SD} = 0.74$).

The table below shows the estimates and the associated uncertainty (95% credible intervals) of occupancy and detection parameters.

Parameter	Mean	Lower 95% CI	Upper 95% CI
mu.psi	0.10	0.04	0.17
mu.p	0.50	0.35	0.63
sd.psi	0.80	0.69	0.89
sd.p	0.74	0.64	0.85

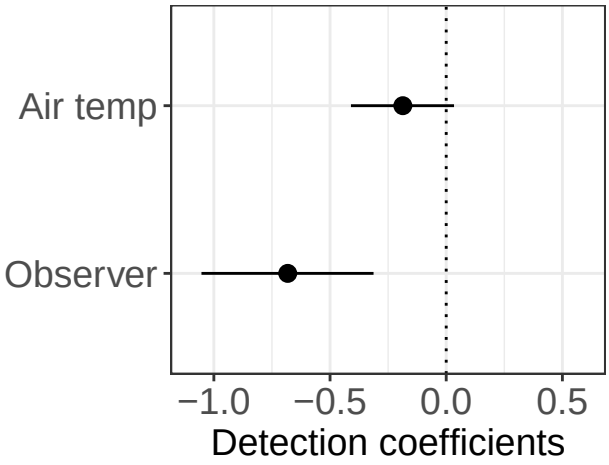
2 Detection process

Detection probability was modelled as a function of observer ID (LP or RC) and air temperature recorded during each survey. The equation for the detection sub-model can be written as

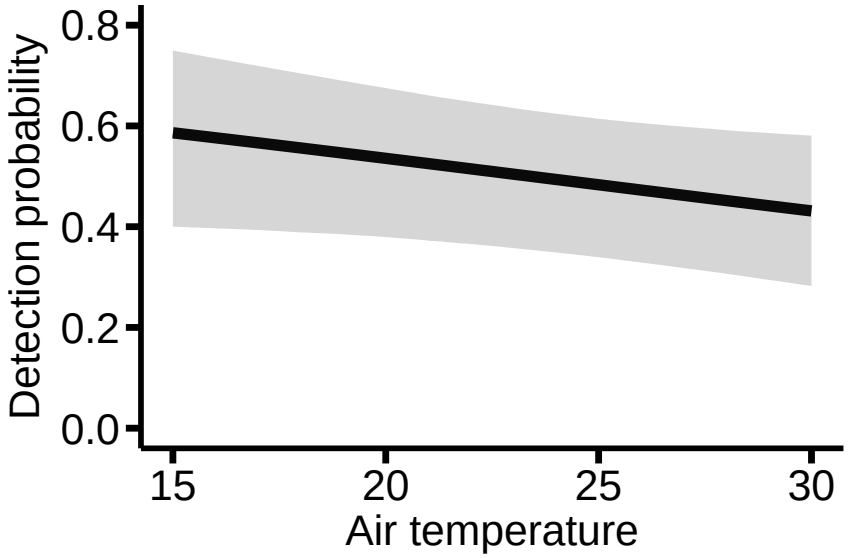
$$p_{ijk} = \alpha_0 + \alpha_1 * observerID_{ij} + \alpha_2 * airtemp_{ij}$$

where p_{ijk} is the detection probability of a species k at site i in survey j.

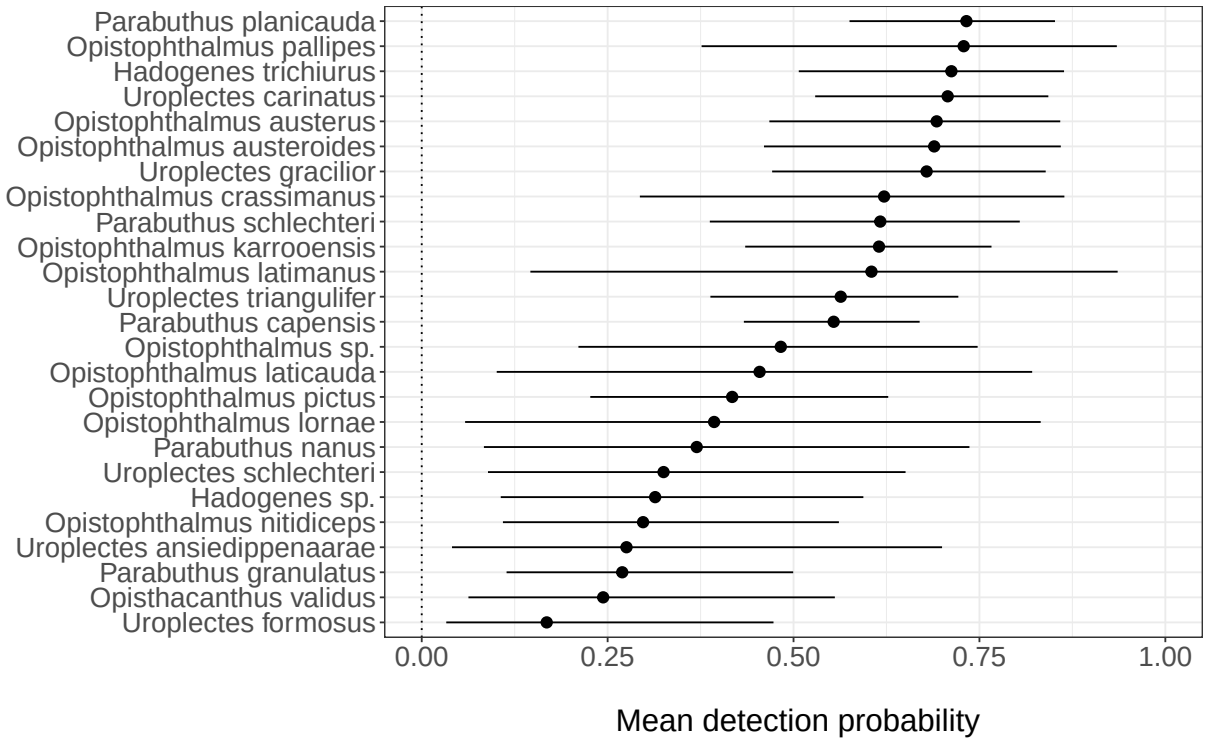
Below is a plot of the standardised magnitude of the detection coefficients (mean ± 95% CI). The results show that detection probability increased as air temperature decreased. Species detectability differed with observer identification with observer 2 (RC) having a significantly lower coefficient.



The relationship between species detectability and air temperature can be visualised in the figure below showing the mean and 95% credible intervals.



Mean detection probability was calculated for each species and ranged from 0.17 to 0.73 with *Parabuthus planicauda* being the most detectable species and *Uroplectes formosus* being the least detectable. Below is a plot of mean detection for each species (plotted with the 95% credible intervals).



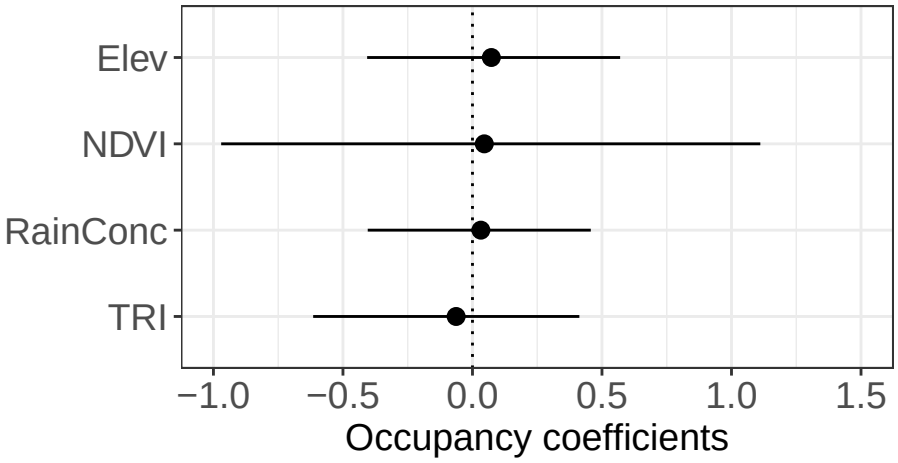
3 Occupancy process

Occupancy probability was modelled as a function of four covariates measured in each pentad: NDVI, rainfall concentration, elevation and terrain ruggedness index (TRI). See Appendix B for maps of each covariate illustrated across the BioGaps study area. The equation for the occupancy sub-model can be written as

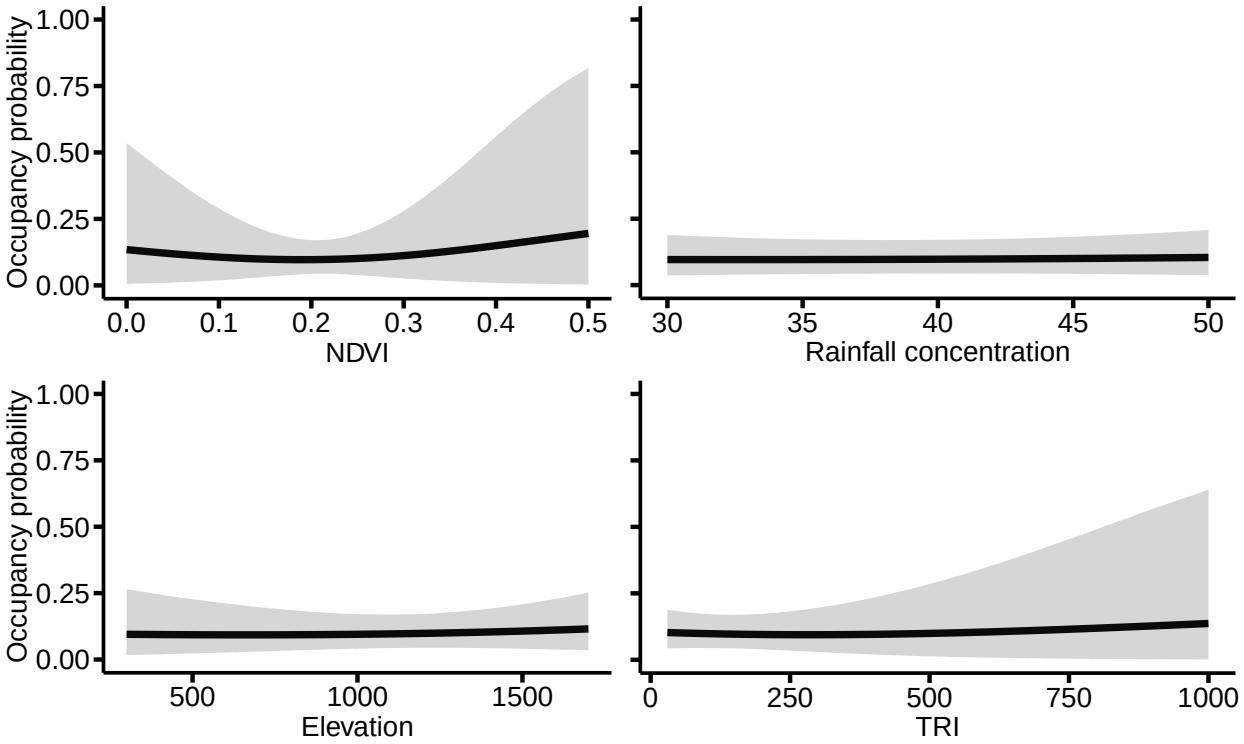
$$\psi_{ik} = \beta_0 + \beta_1 * NDVI_i + \beta_2 * rainConc_i + \beta_3 * elev_i + \beta_4 * TRI_i$$

where ψ_{ik} is the occupancy probability of a species k at site i.

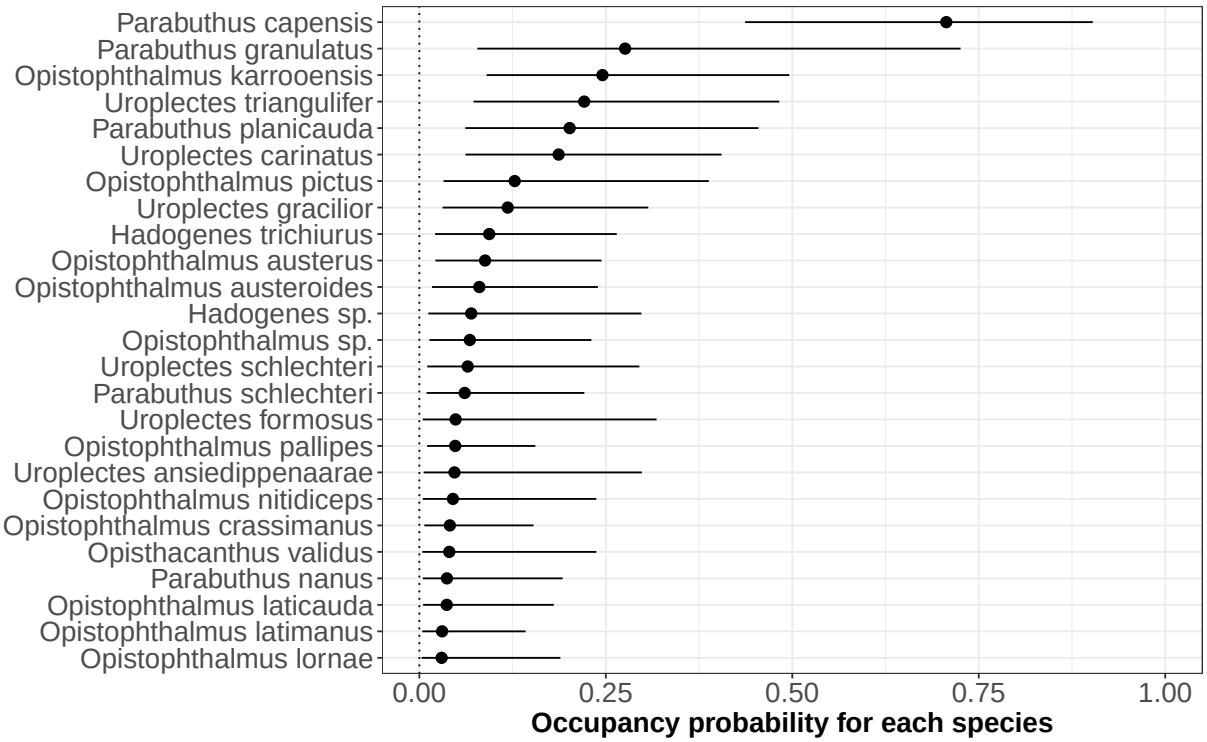
Below is a plot of the standardised magnitude of the each of the detection coefficients (mean ± 95% CI). The results show that, at the community level, the environmental covariates are not significant predictors of species occupancy because the coefficients have CIs that overlap with zero. This does not mean that individual species themselves did not respond to environmental variables (see section on random effects below).



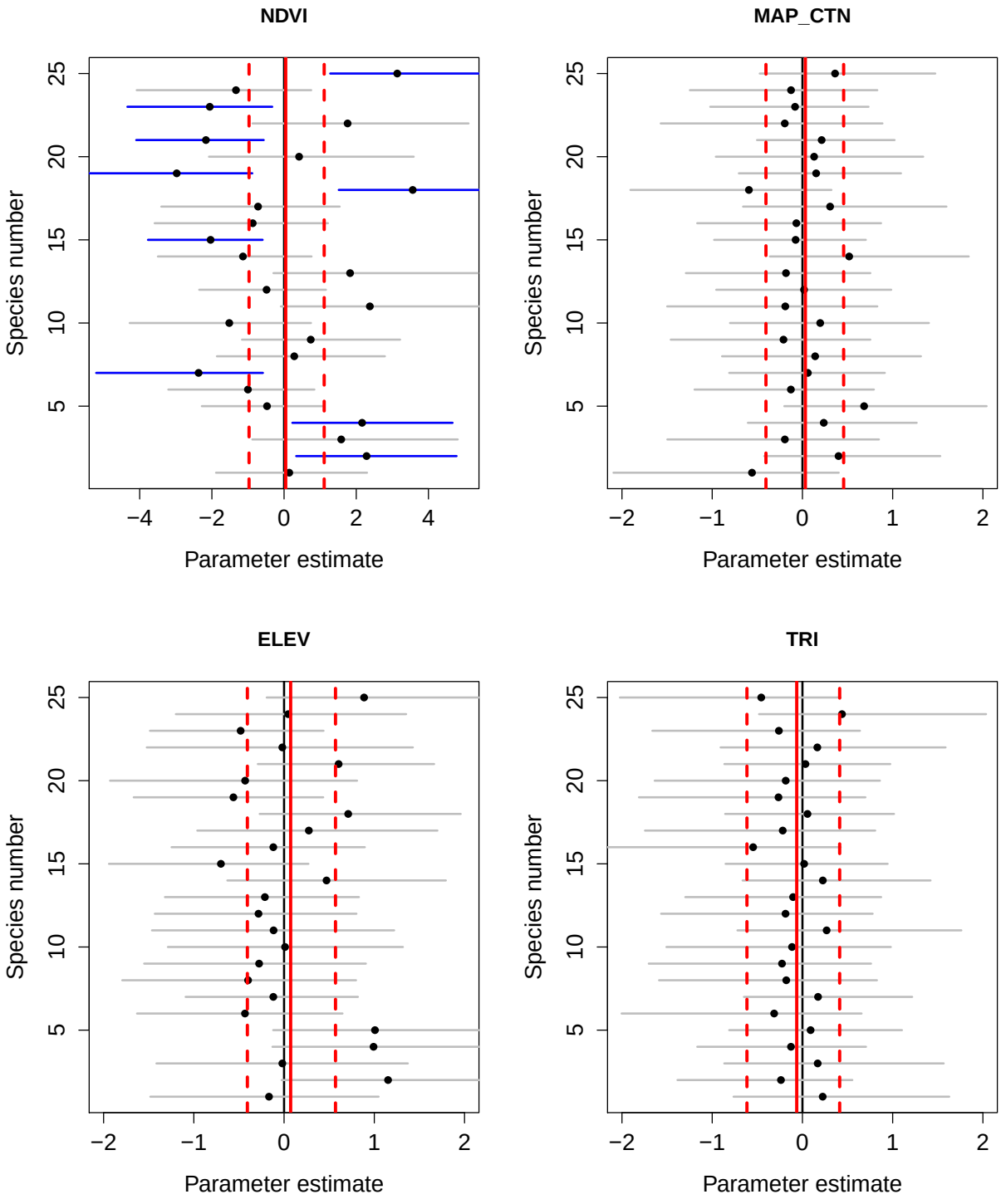
The relationship between species occupancy and NDVI, rainfall concentration, elevation and TRI can be visualised in the figure below showing the mean and 95% credible intervals.



Mean occupancy probability was calculated for each species and ranged from 0.03 to 0.71 with *Parabuthus capensis* having the highest occupancy and *Opistophthalmus lornae* having the lowest. Below is a plot of mean detection for each species (plotted with the 95% credible intervals).



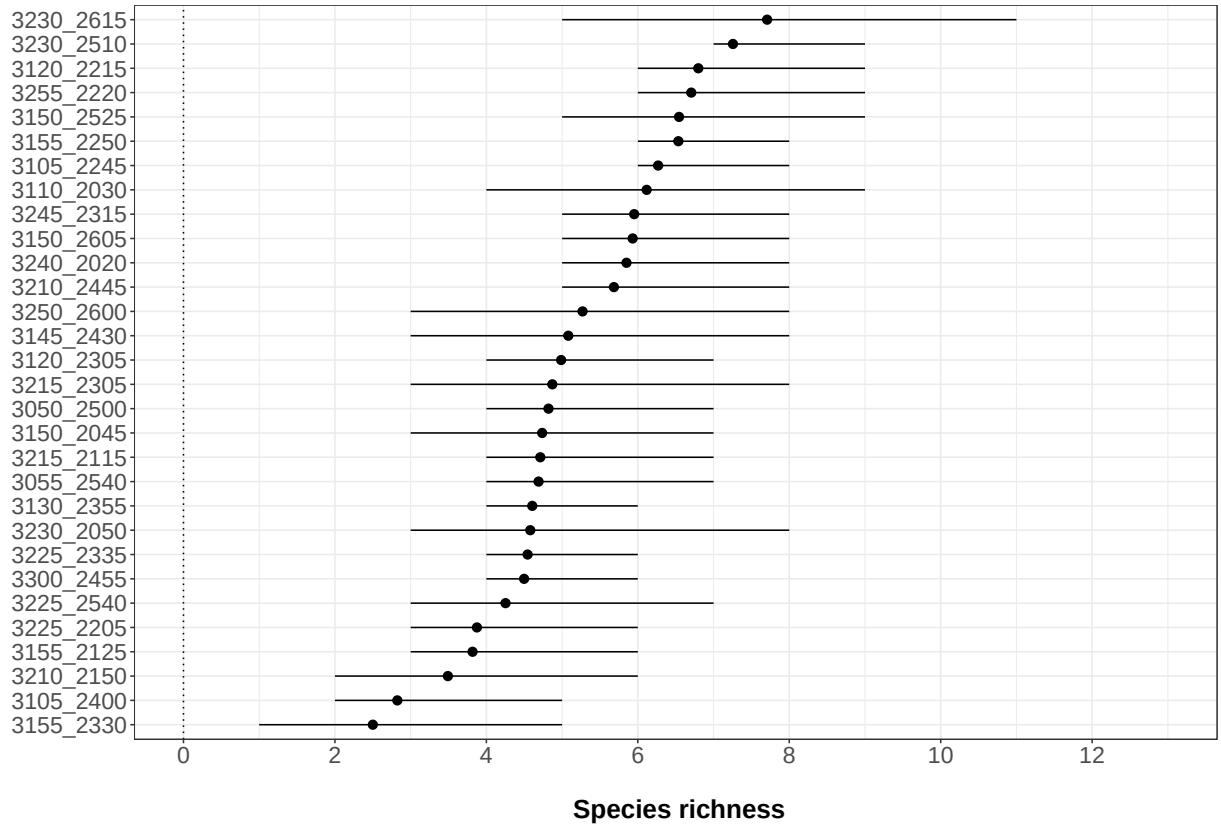
Species were modelled as a random effect in the occupancy models and so we were able to determine the relationship between occupancy and environmental covariates for each species. The plots below illustrate the species-level coefficients for the four environmental covariates. Blue lines indicate a significant relationship (i.e., 95% CIs do not overlap with zero). From the NDVI plot we can see that there were 4 species that had higher occupancy probability in areas with a higher primary productivity (with high NDVI) and 5 species that had a higher occupancy probability in dry areas with low primary productivity (low NDVI). There was little support for a significant relationship between occupancy and the remaining three covariates.


NDVI
MAP_CTN
ELEV
TRI
Species number
Parameter estimate
5
10
15
20
25
−4
−2
0
2
4
−2
−1
0
1
2

4 Species richness

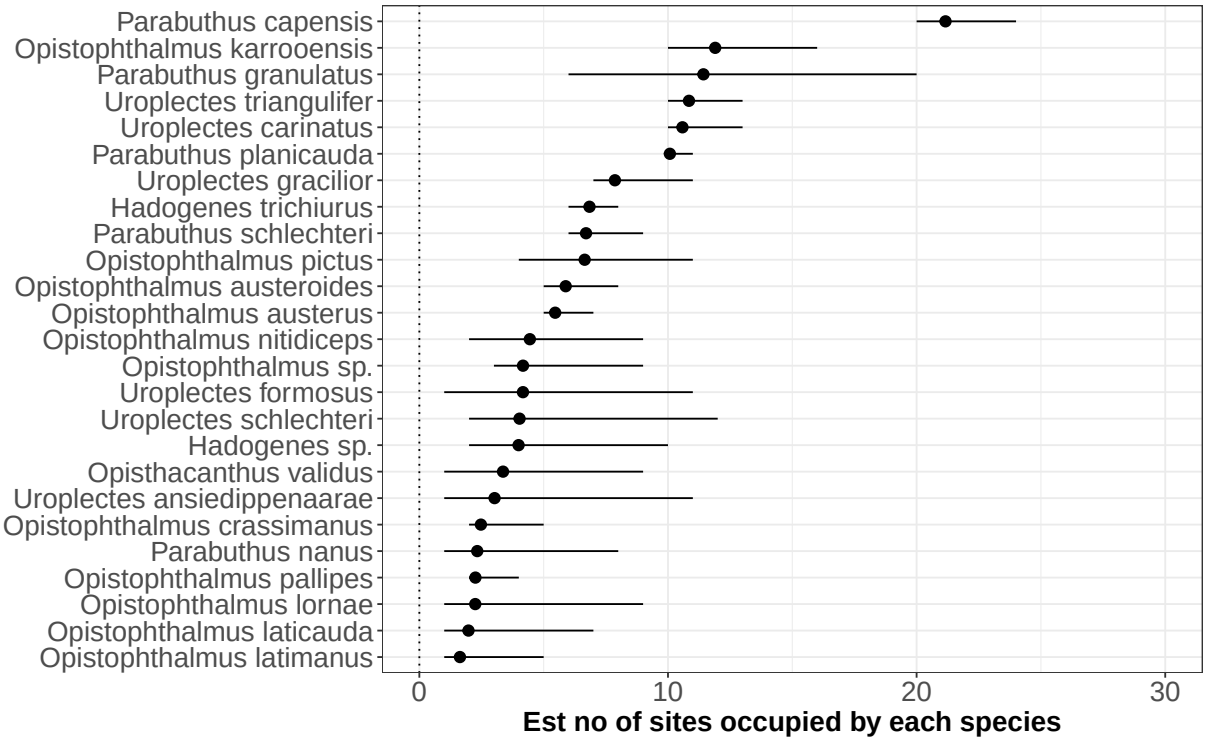
4.1 Species richness at sampled sites

Below is a plot of mean estimated species richness for each of the sampled pentads. They include the 95% CIs. The results show that richness was highest with 8 species in pentad 3230_2615 and lowest with 3 species in pentad 3155_2330.



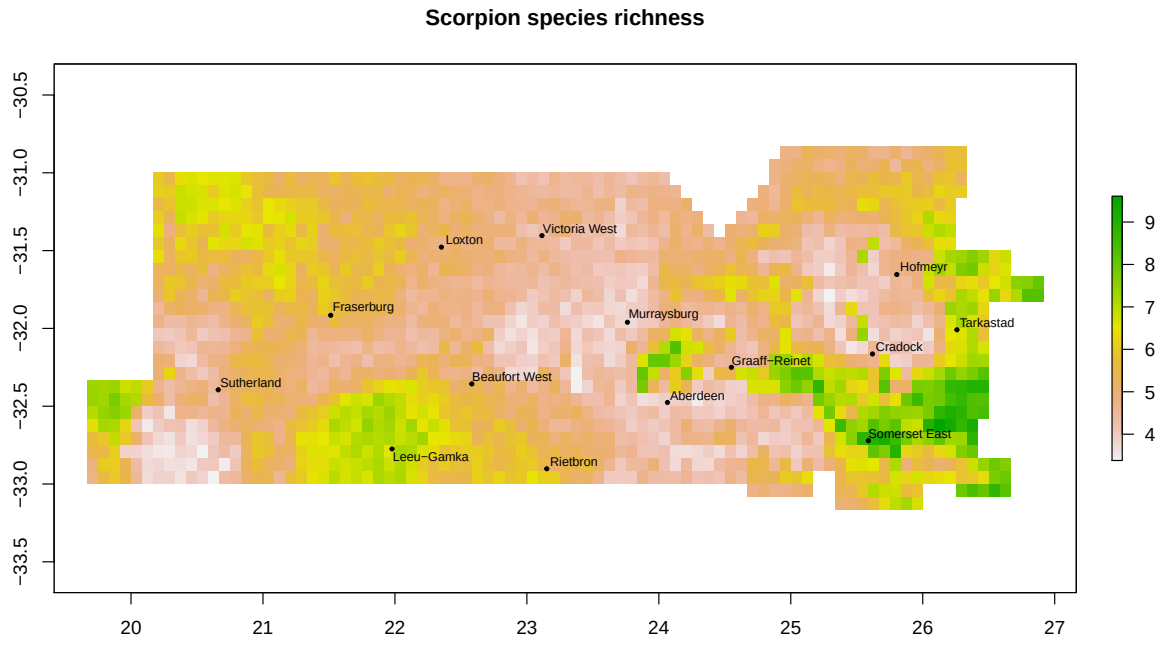
4.2 Number of occupied sites by each species

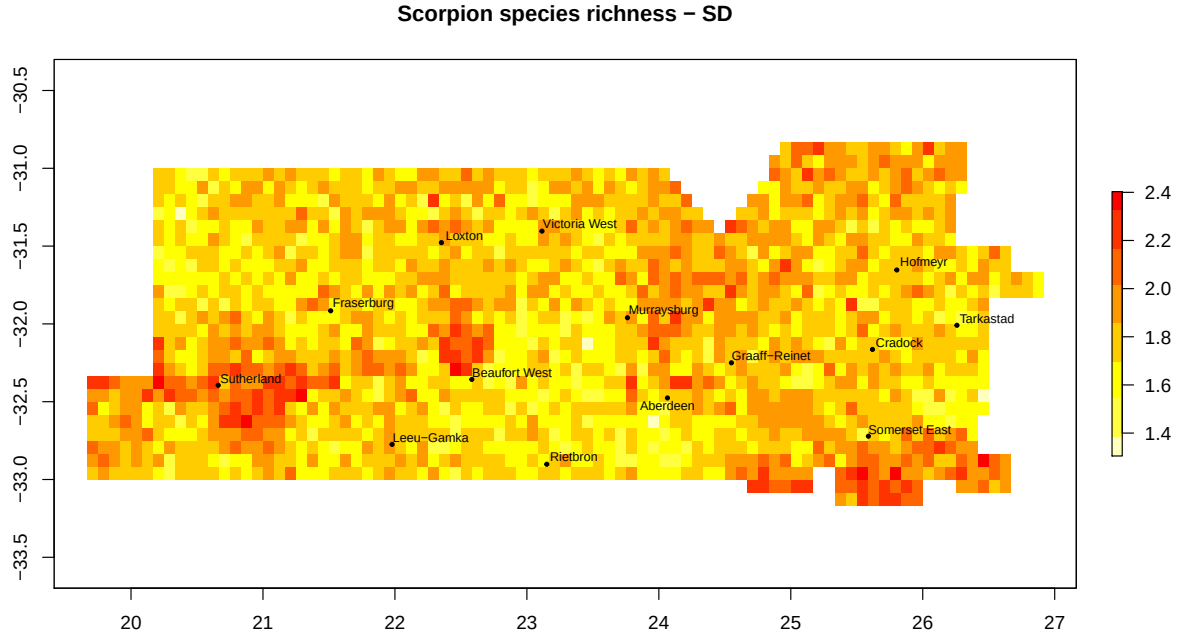
The models also allowed us to estimate the number of sites that the each species occurred within.



4.3 Species richness and standard deviation map

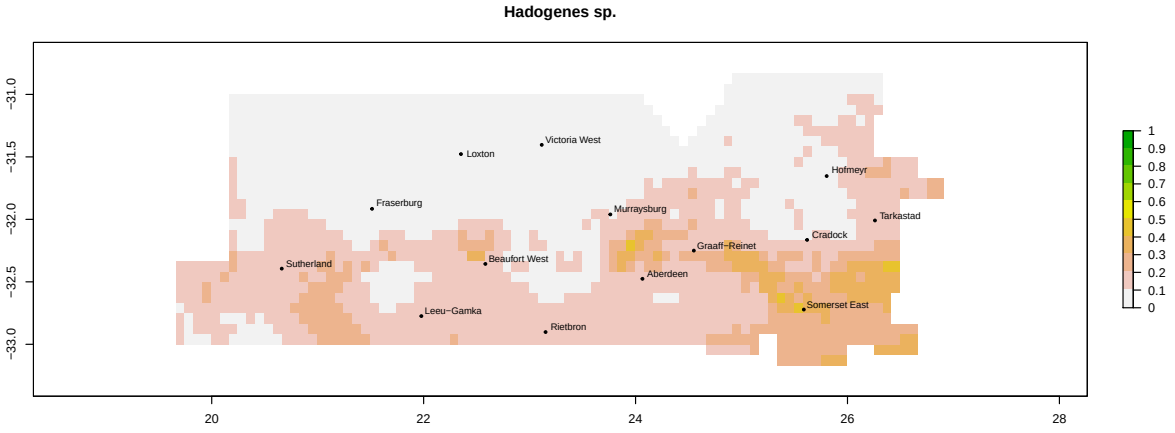
By combing the occupancy probability estimates of each species we were able to produce a predictive map of Scorpion species richness. The map below also shows the uncertainty associated with these estimates using standard deviation. Species richness was highest in the pentads located in the furthest eastern sections of the study area.

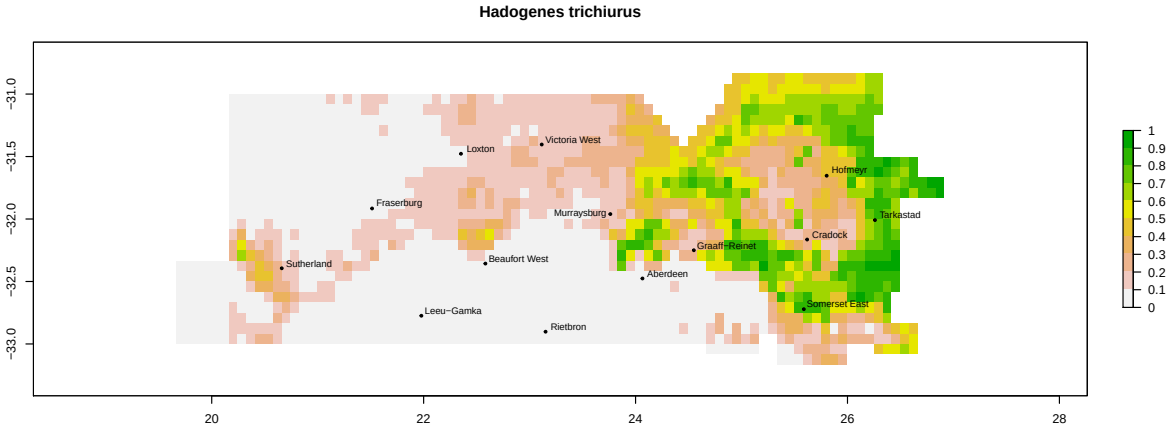


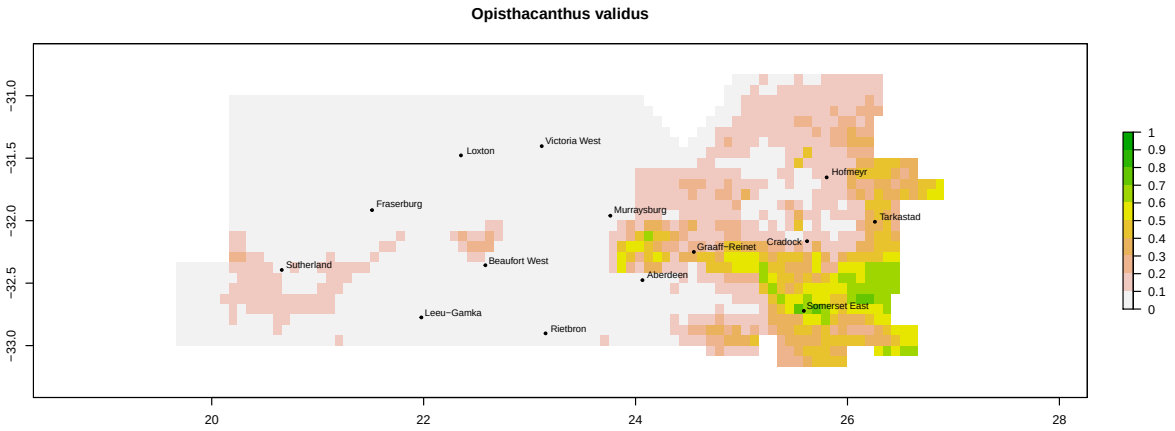


5 Species occurence maps

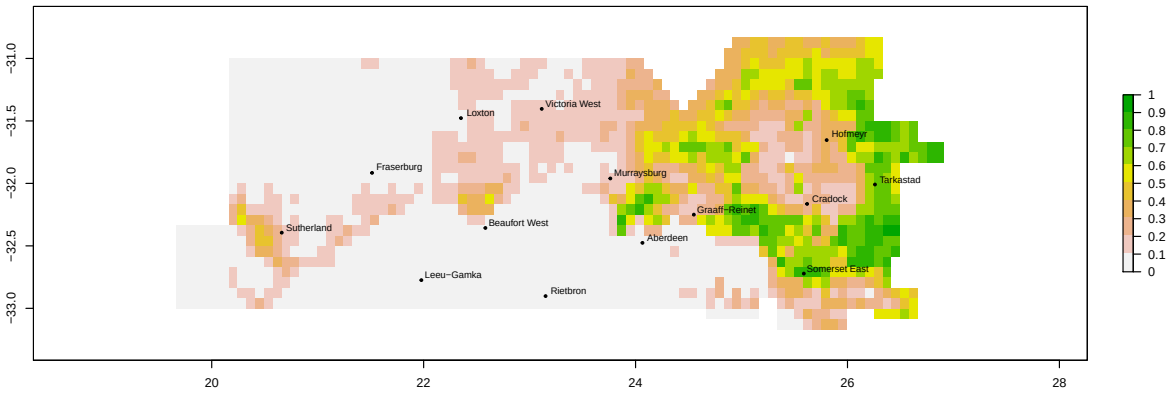
5.1 Maps of mean occurence for individual species



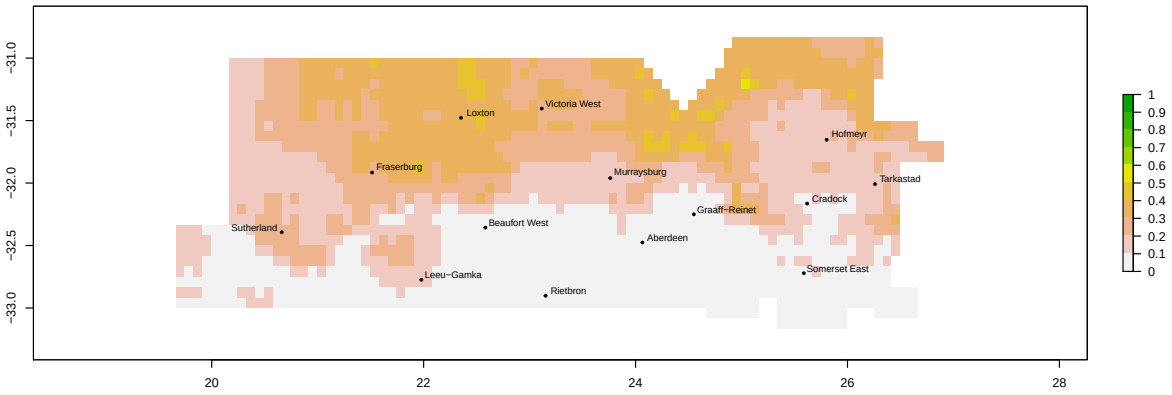




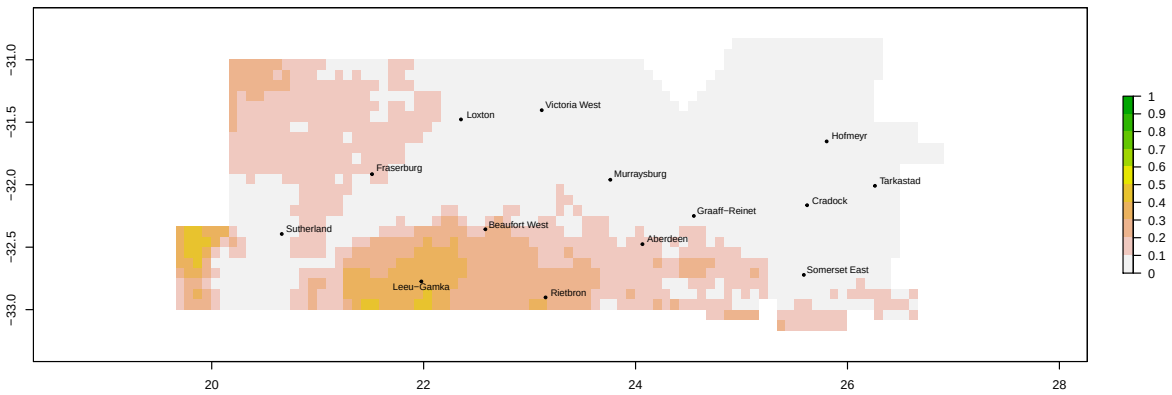
Opistophthalmus austeroides



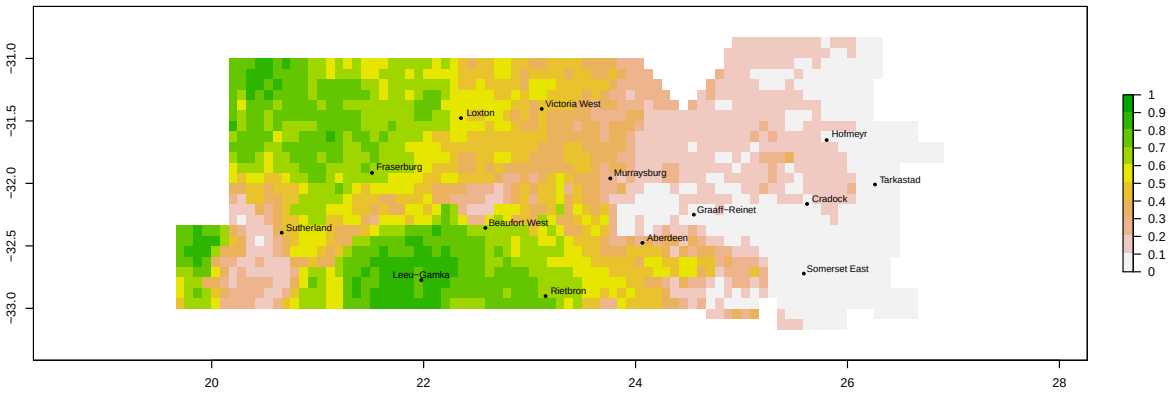
Opistophthalmus austerus



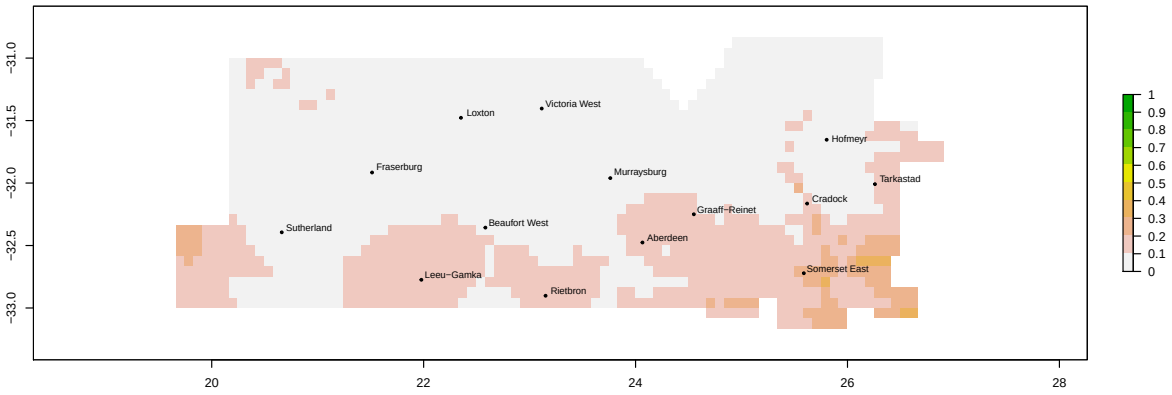
Opistophthalmus crassimanus



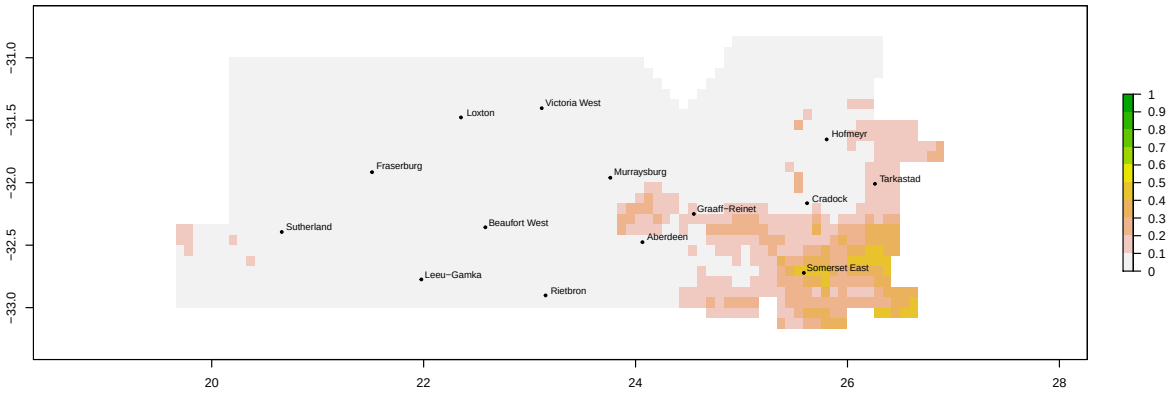
Opistophthalmus karrooensis



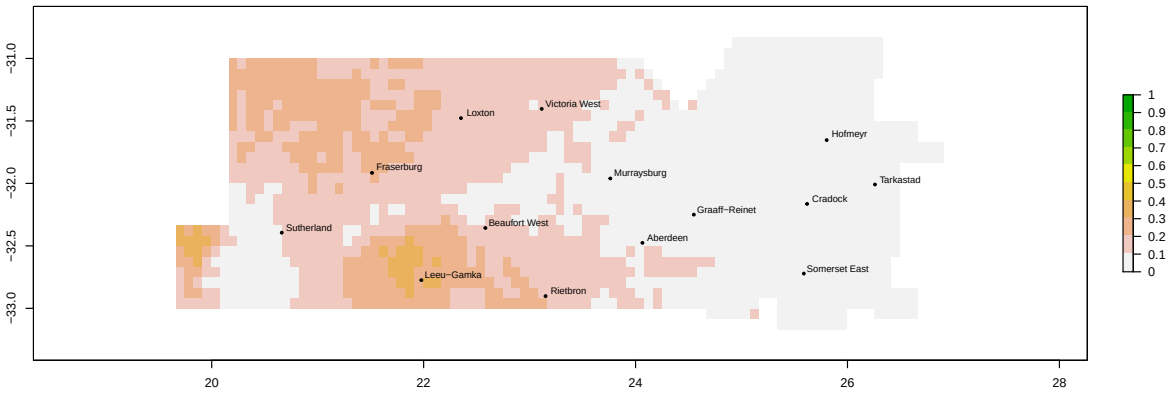
Opistophthalmus laticauda



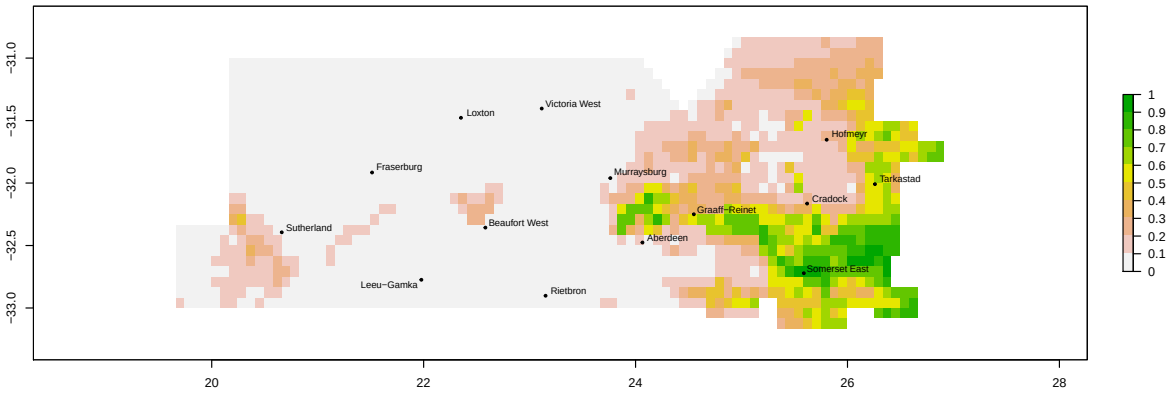
Opistophthalmus latimanus



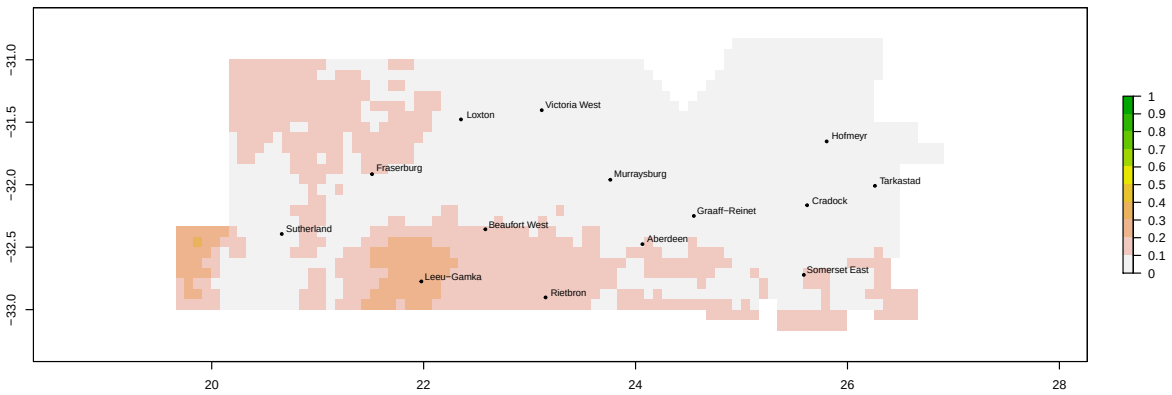
Opistophthalmus lornae



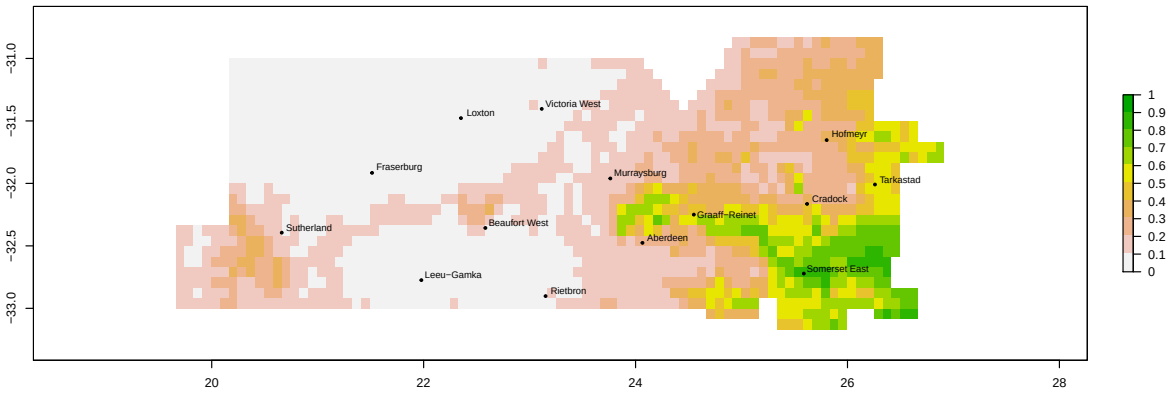
Opistophthalmus nitidiceps



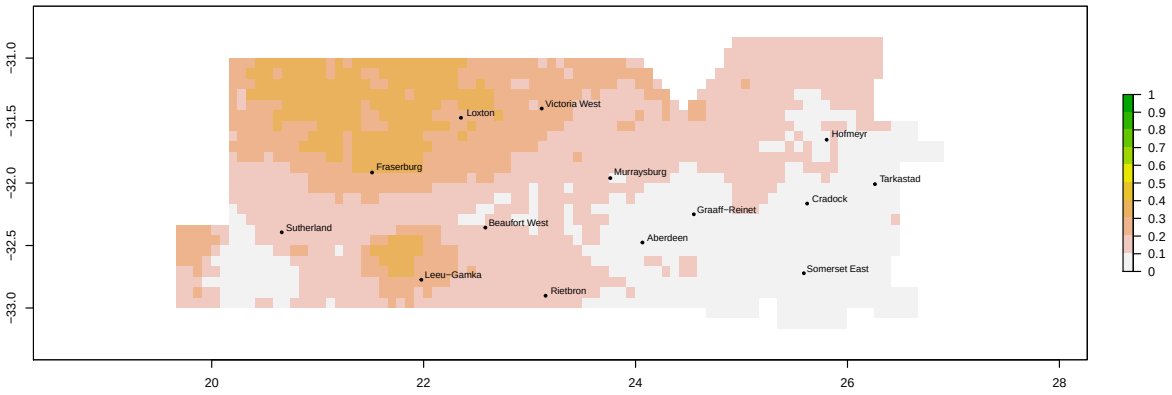
Opistophthalmus pallipes



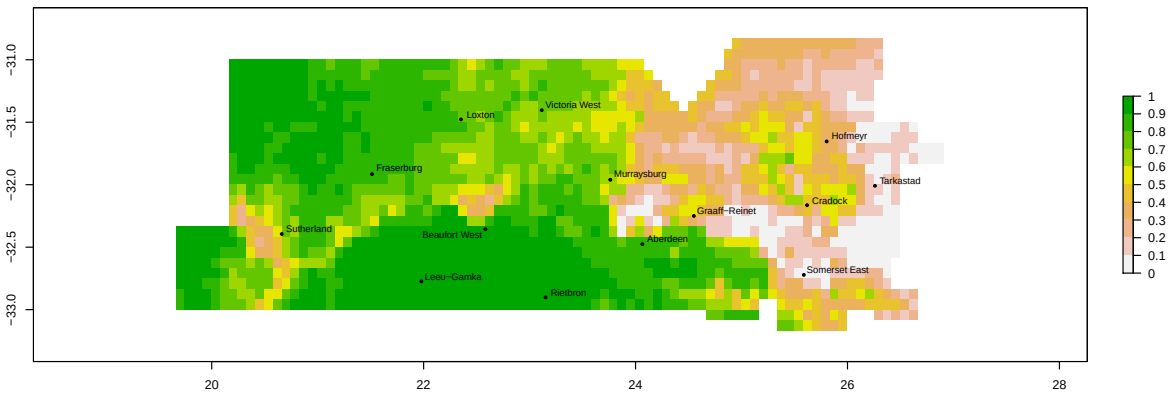
Opistophthalmus pictus



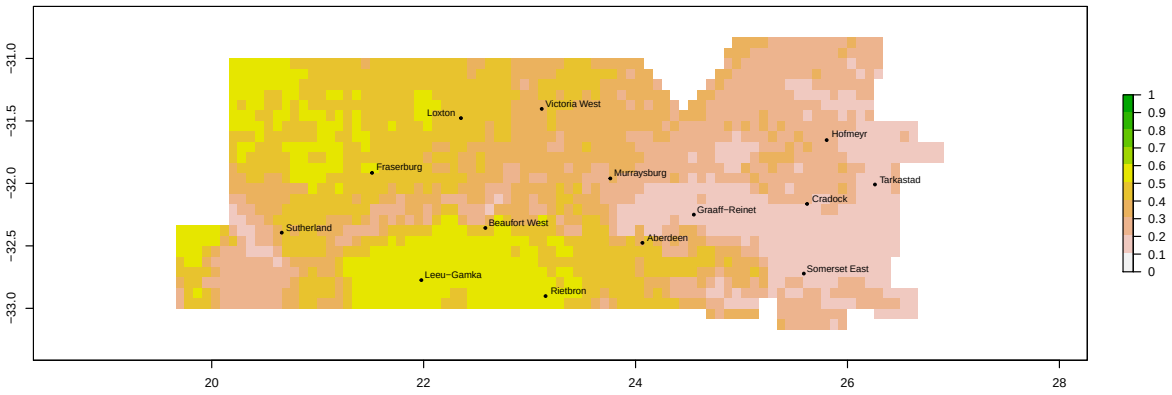
Opistophthalmus sp.



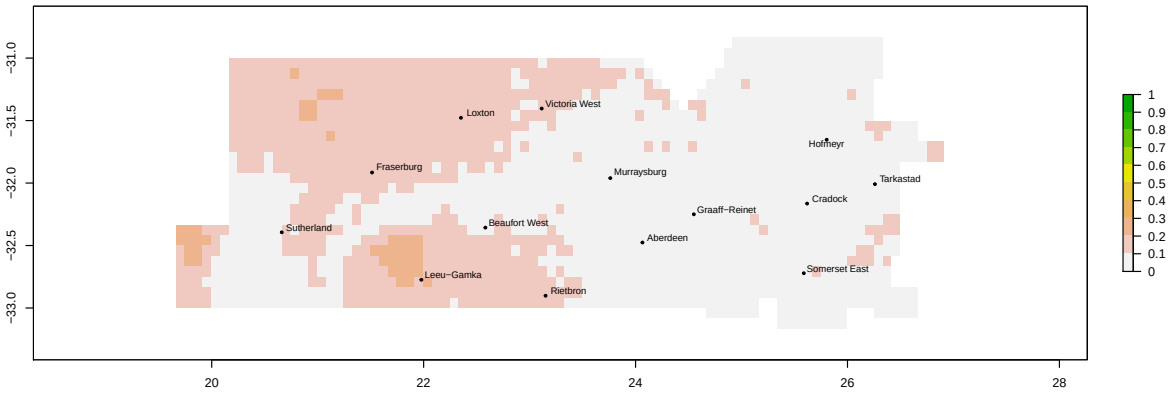
Parabuthus capensis



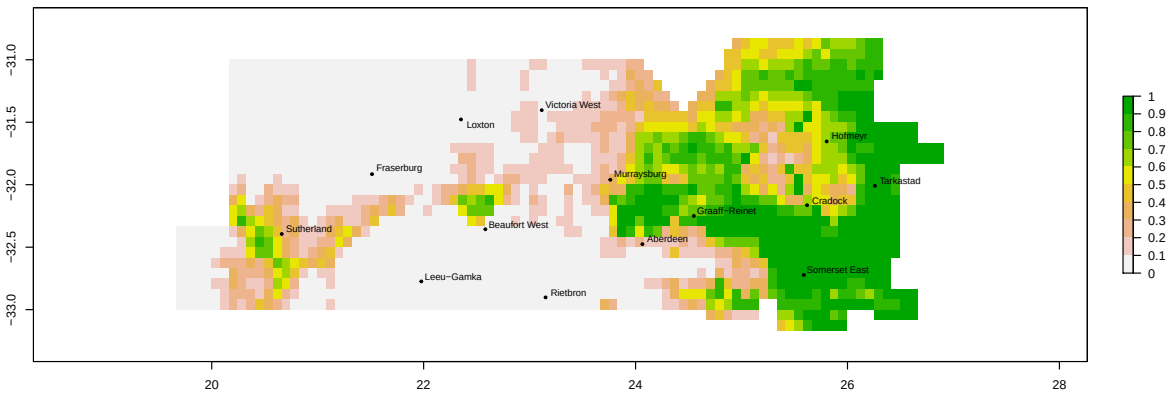
Parabuthus granulatus



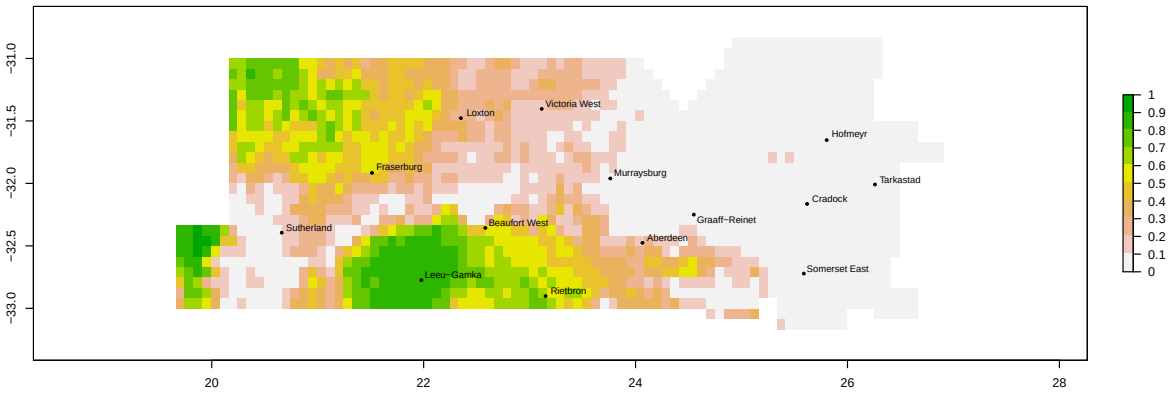
Parabuthus nanus



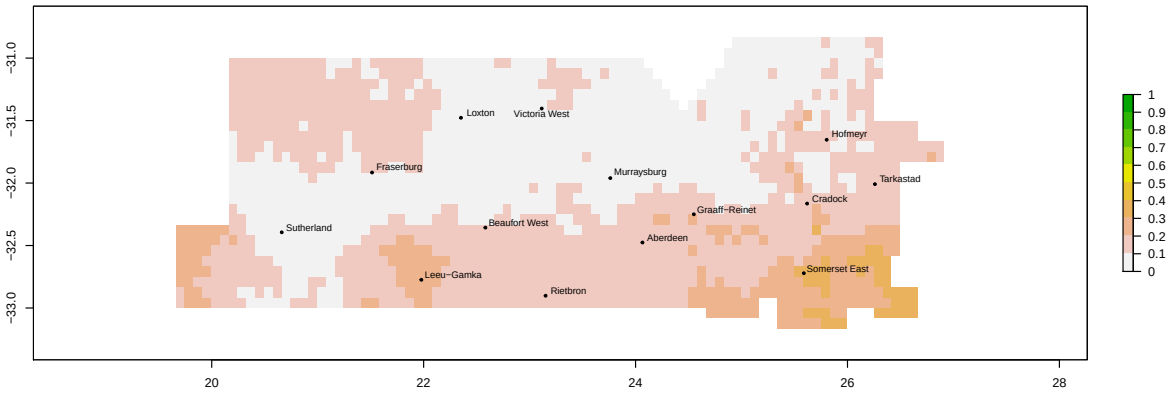
Parabuthus planicauda



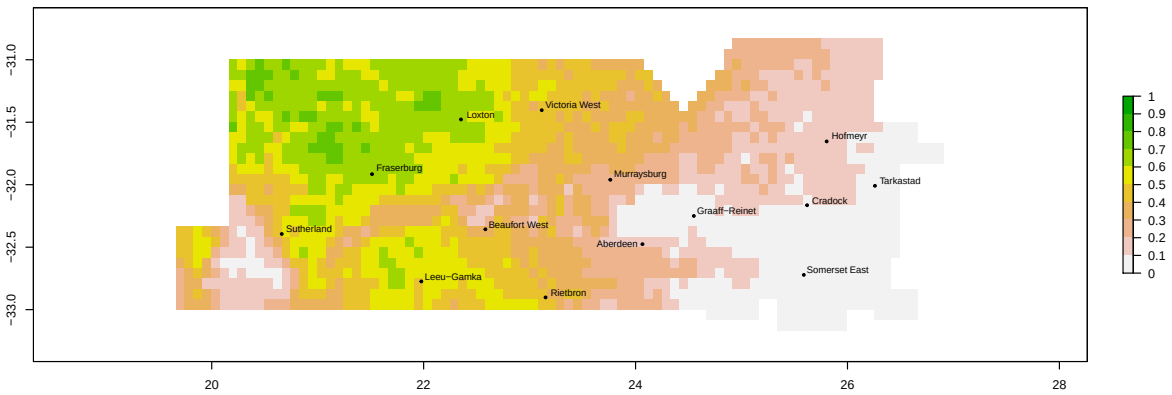
Parabuthus schlechteri



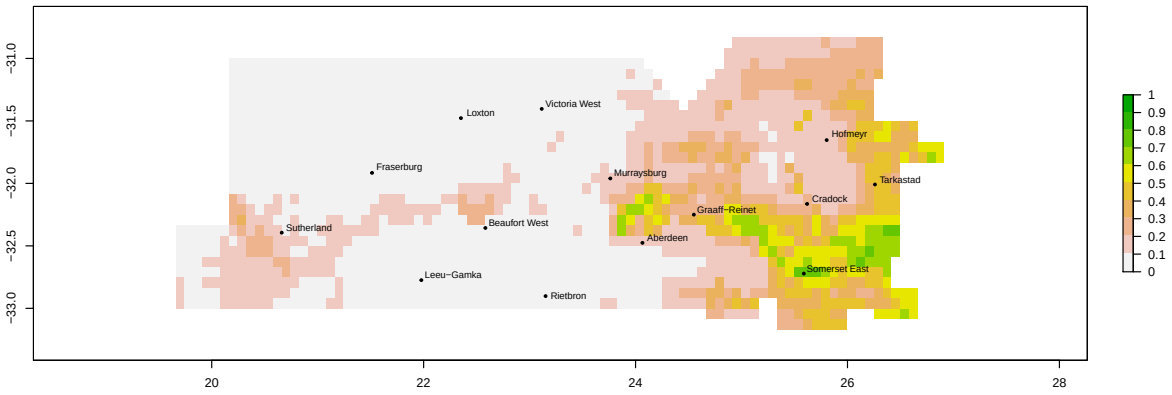
Uroplectes ansiedippenaarae



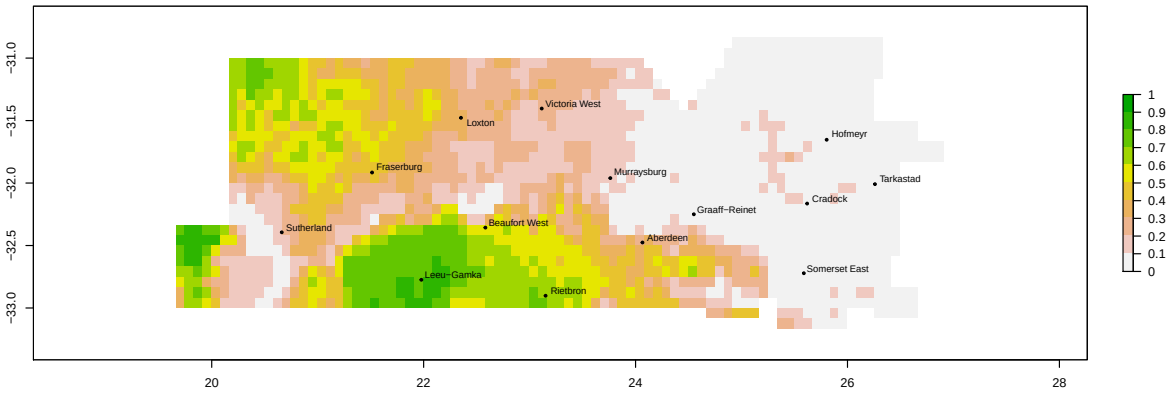
Uroplectes carinatus



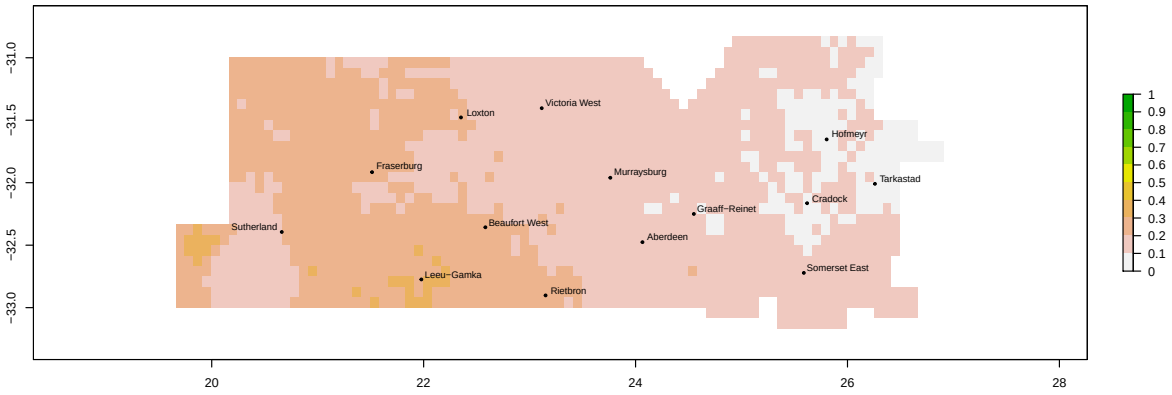
Uroplectes formosus

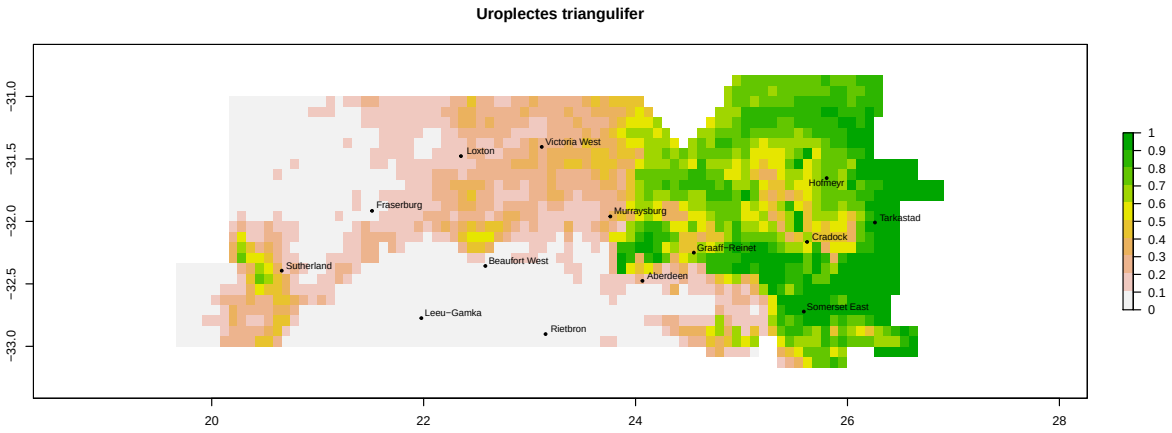


Uroplectes gracilior

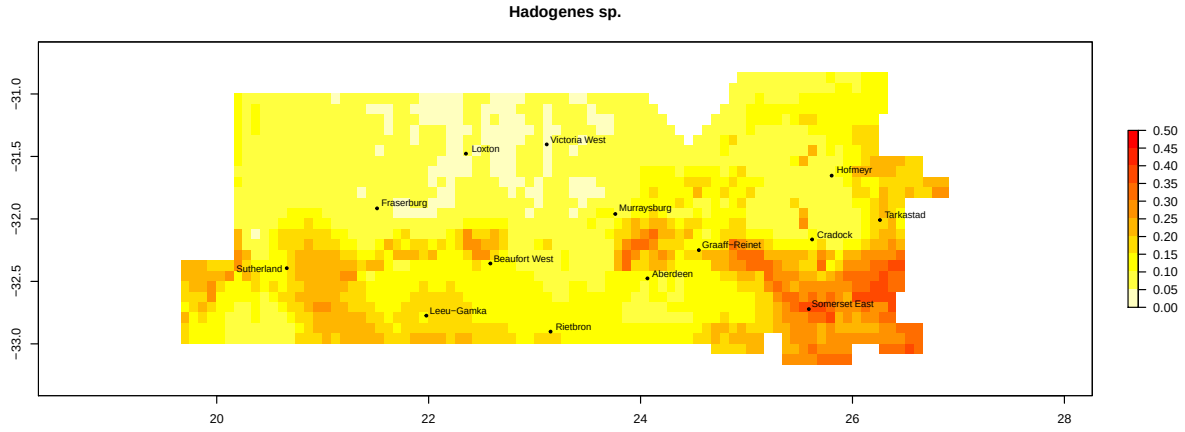


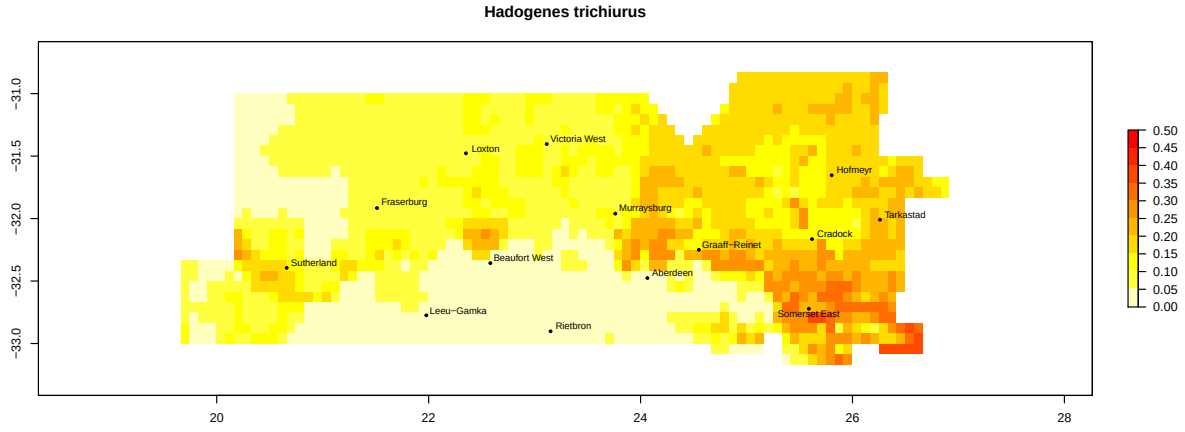
Uroplectes schlechteri

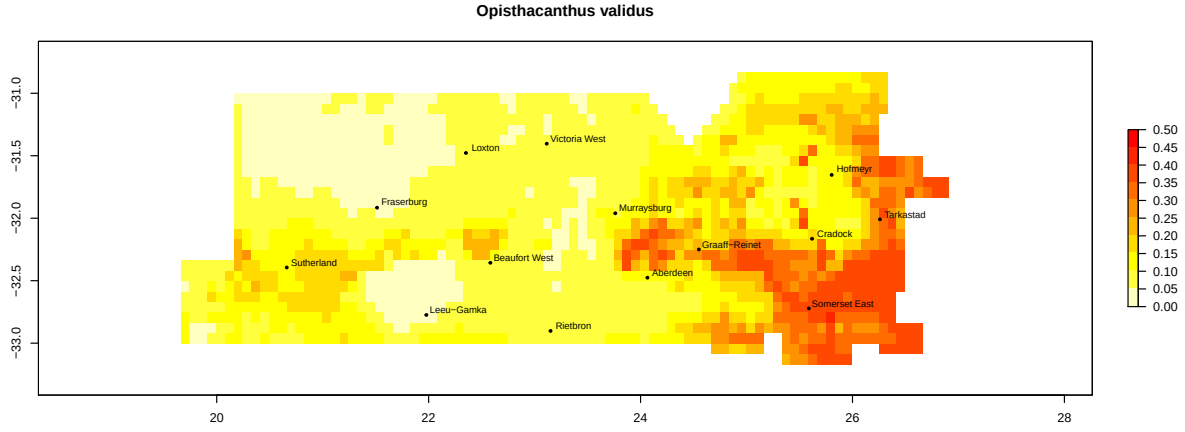



Uroplectes triangulifer
−31.0
−31.5
−32.0
−32.5
−33.0
20
22
24
26
28
Loxton
Victoria West
Fraserburg
Murraysburg
Hofmeyr
Tarkastad
Cradock
Graaff−Reinet
Sutherland
Beaufort West
Aberdeen
Somerset East
Leeu−Gamka
Rietbron
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

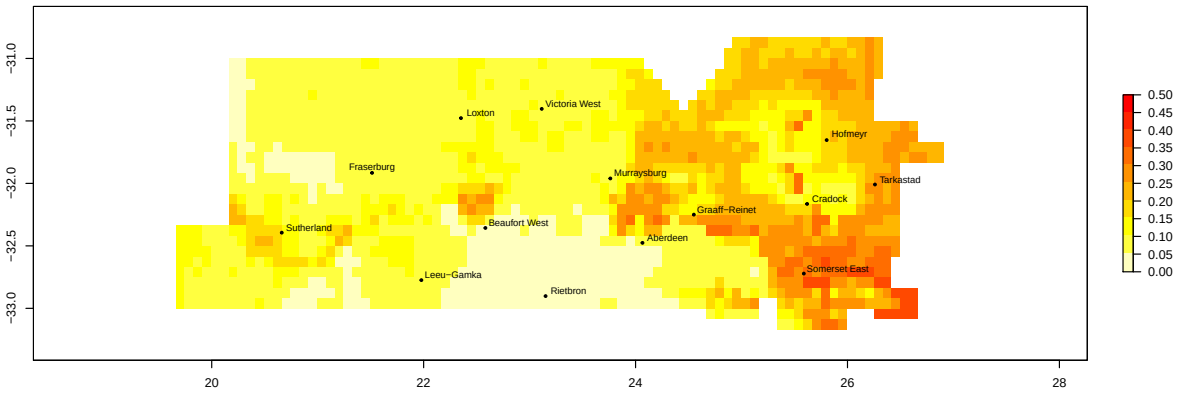
5.2 Maps of standard deviation of mean occurence for individual species



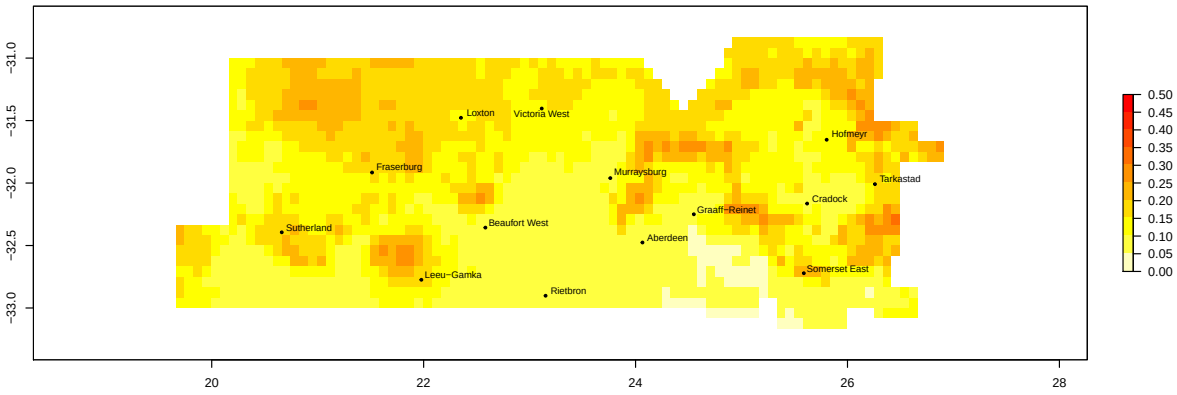




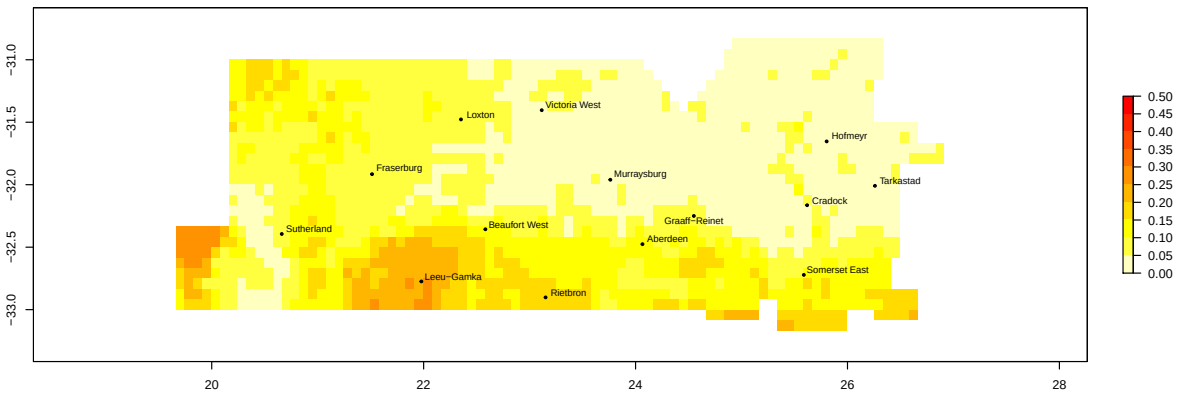
Opistophthalmus austeroides

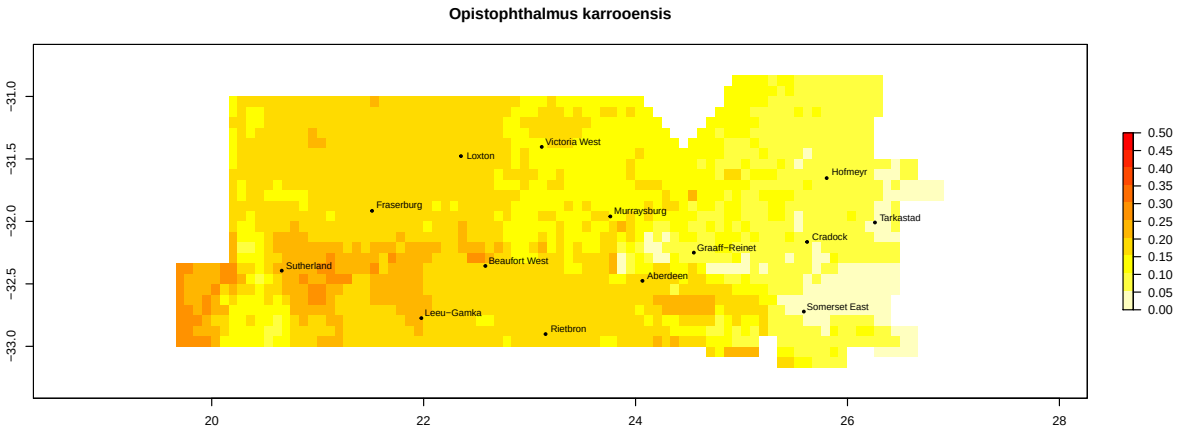


Opistophthalmus austerus



Opistophthalmus crassimanus




Opistophthalmus karrooensis
Loxton
Victoria West
Hofmeyr
Fraserburg
Murraysburg
Tarkastad
Cradock
Graaff−Reinet
Sutherland
Beaufort West
Aberdeen
Somerset East
Leeu−Gamka
Rietbron
−31.0
−31.5
−32.0
−32.5
−33.0
20
22
24
26
28
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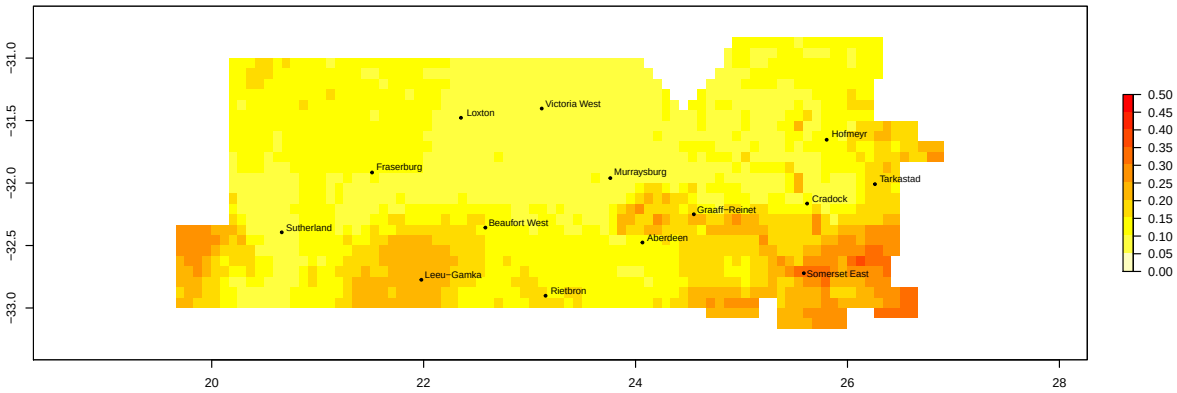
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00


Opistophthalmus laticauda
Loxton
Victoria West
Hofmeyr
Fraserburg
Murraysburg
Tarkastad
Cradock
Graaff−Reinet
Sutherland
Beaufort West
Aberdeen
Somerset East
Leeu−Gamka
Rietbron
−31.0
−31.5
−32.0
−32.5
−33.0
20
22
24
26
28
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0.45
0.40
0.35
0.30
0.25
0.20
0.15
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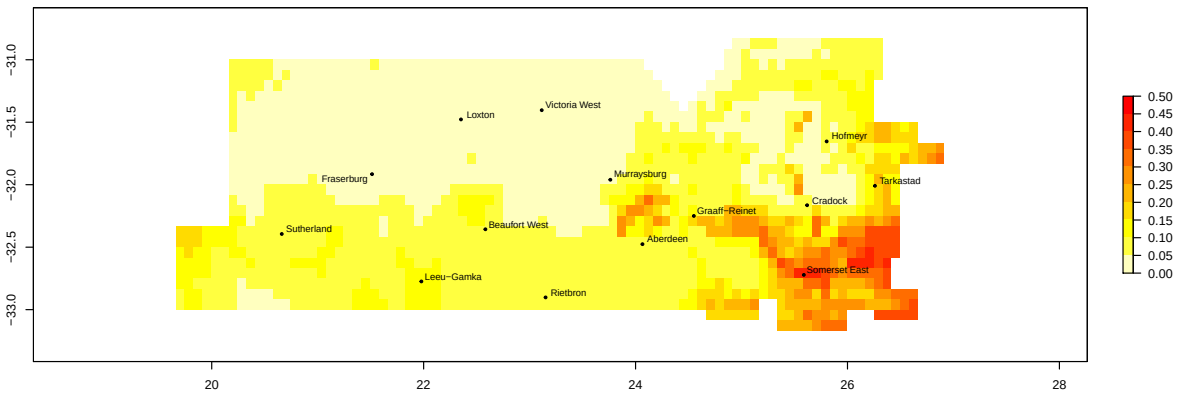
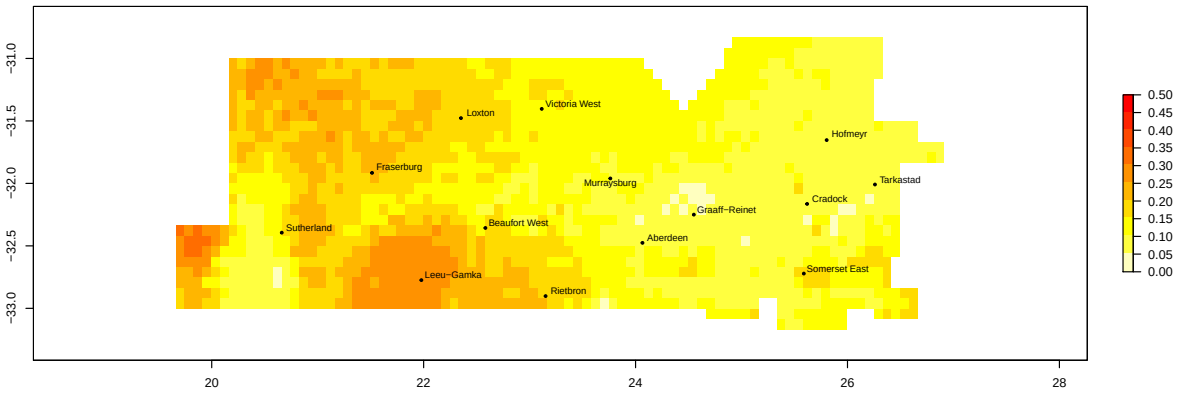
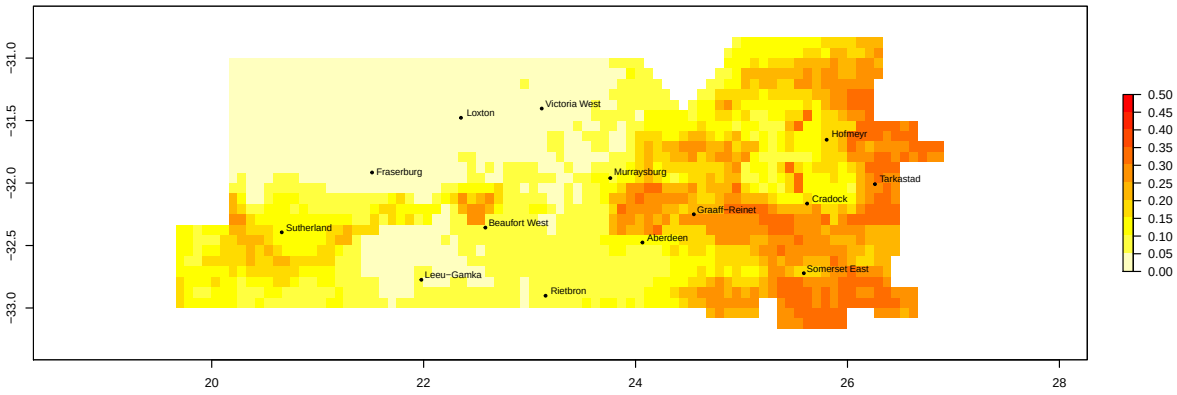
0.05
0.00


Opistophthalmus latimanus
Loxton
Victoria West
Hofmeyr
Fraserburg
Murraysburg
Tarkastad
Cradock
Graaff−Reinet
Sutherland
Beaufort West
Aberdeen
Somerset East
Leeu−Gamka
Rietbron
−31.0
−31.5
−32.0
−32.5
−33.0
20
22
24
26
28
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00

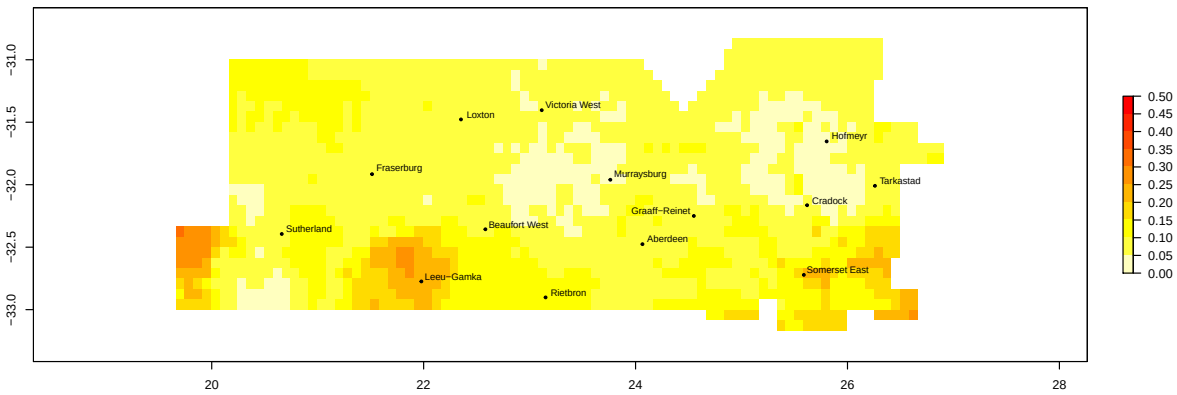
Opistophthalmus lornae



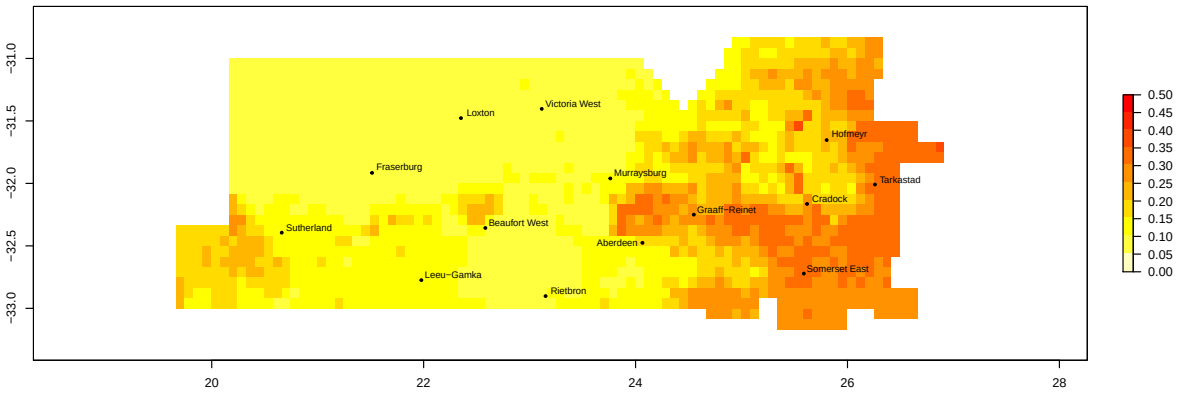
Opistophthalmus nitidiceps



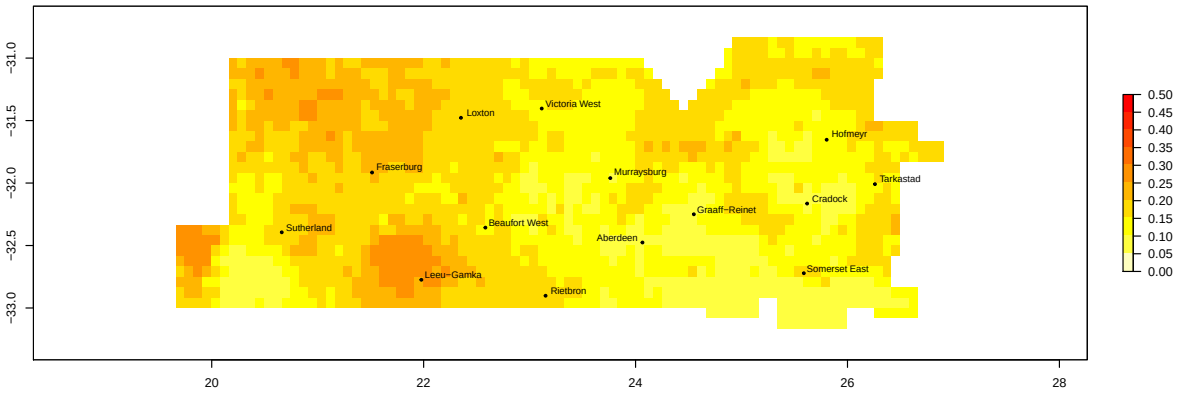
Opistophthalmus pallipes



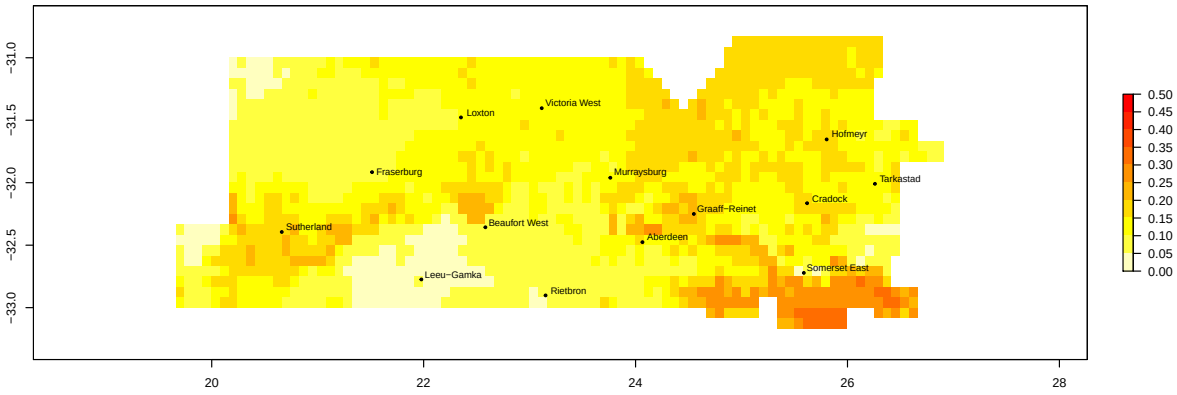
Opistophthalmus pictus



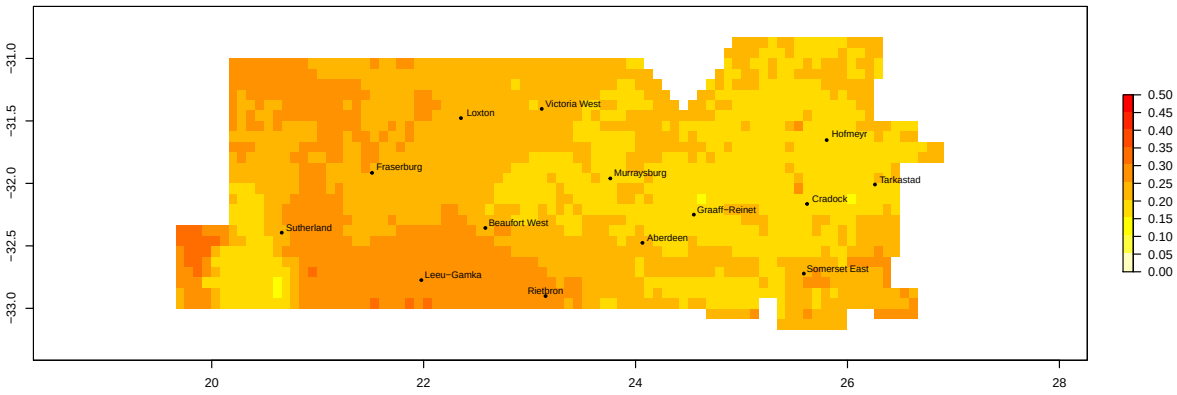
Opistophthalmus sp.



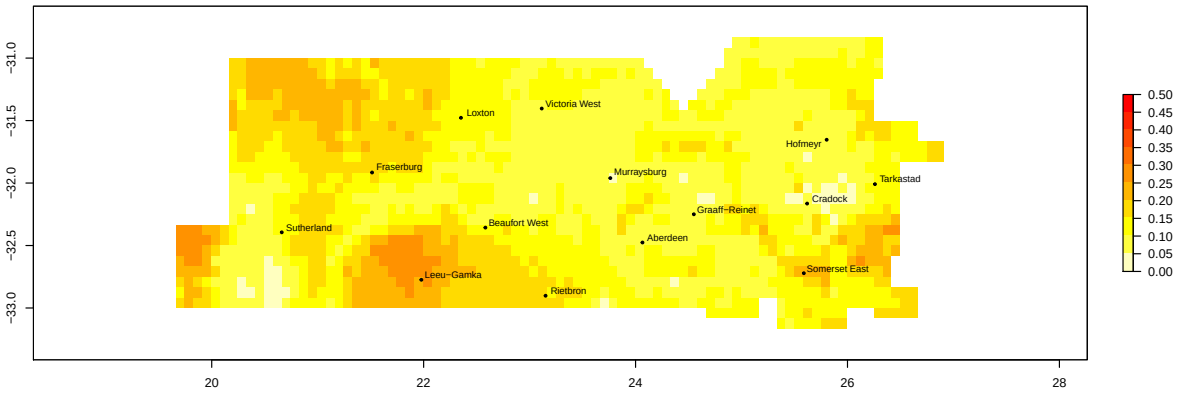
Parabuthus capensis



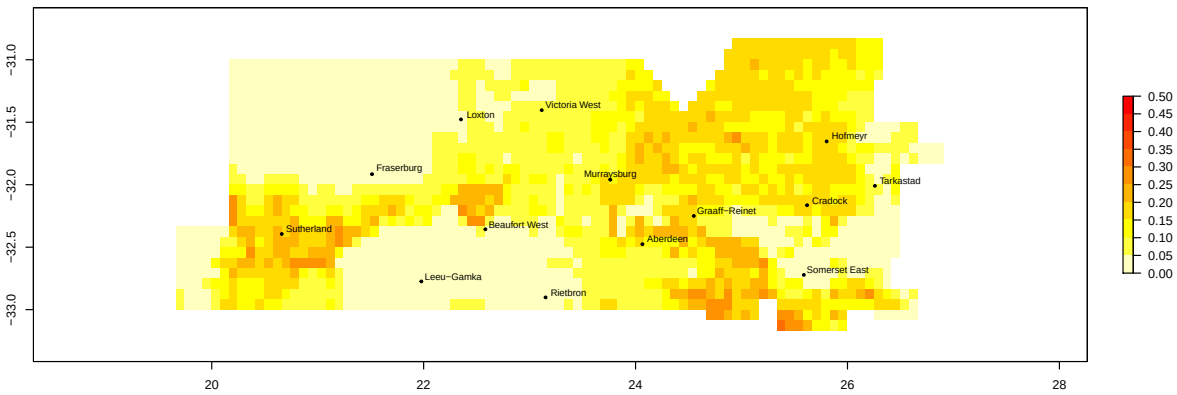
Parabuthus granulatus



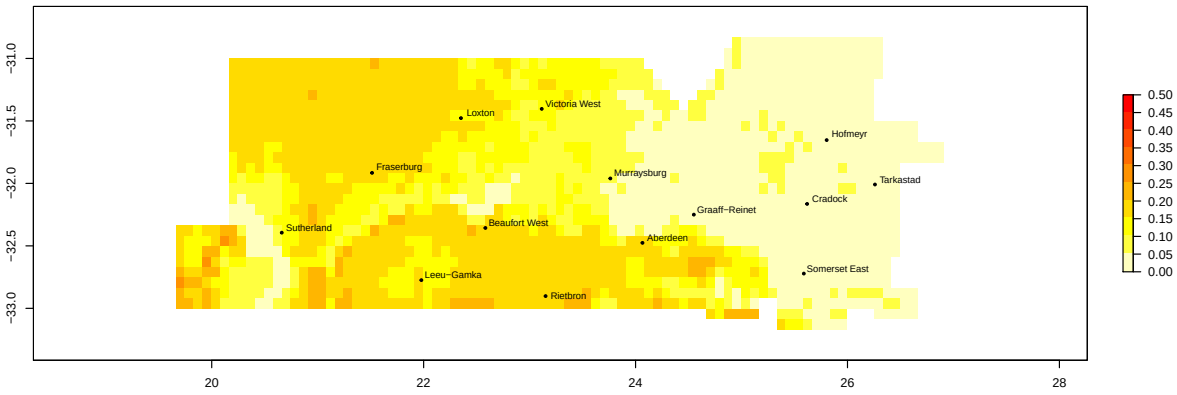
Parabuthus nanus



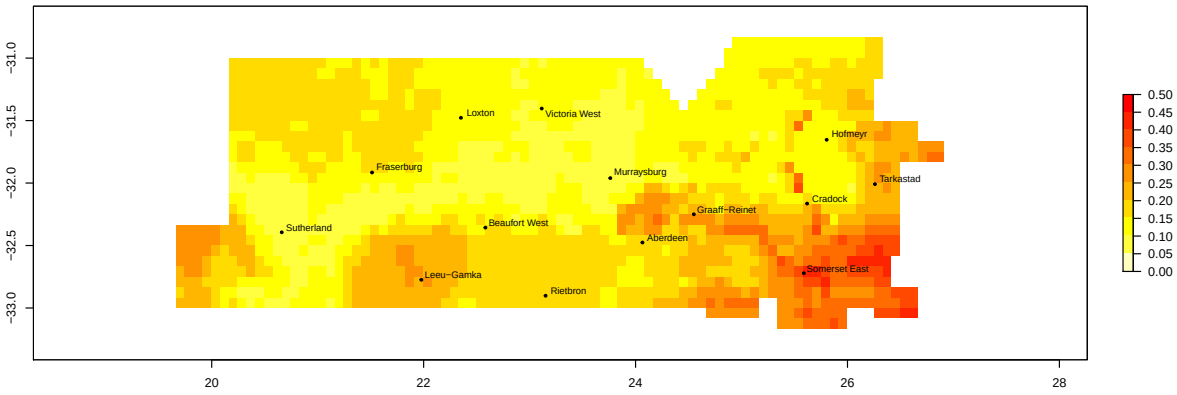
Parabuthus planicauda



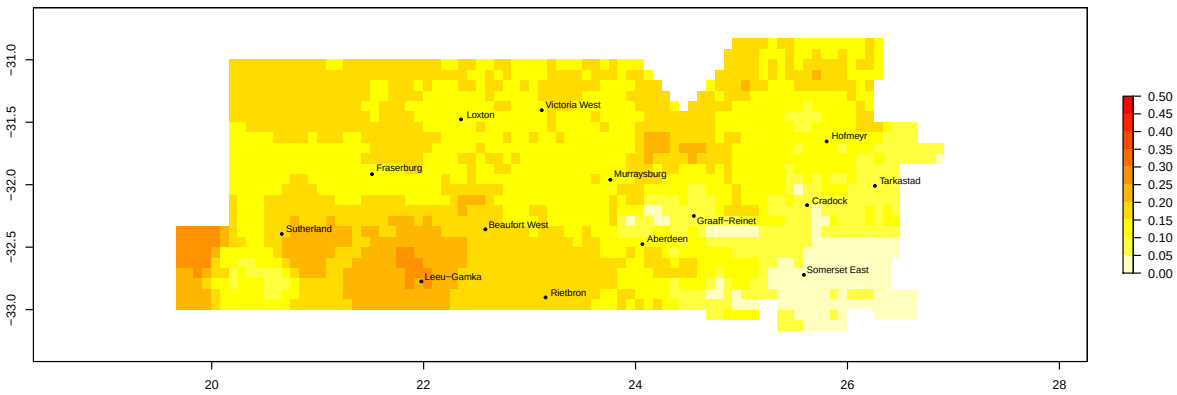
Parabuthus schlechteri



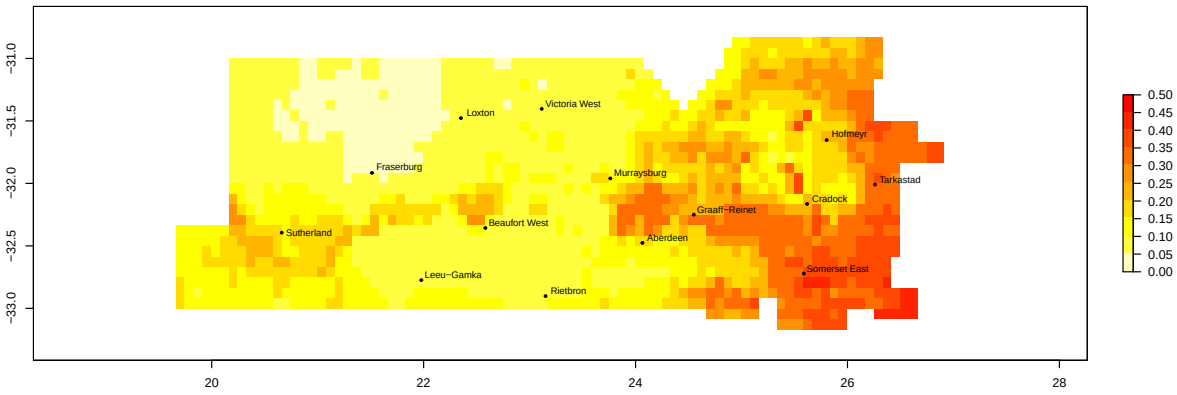
Uroplectes ansiedippenaarae



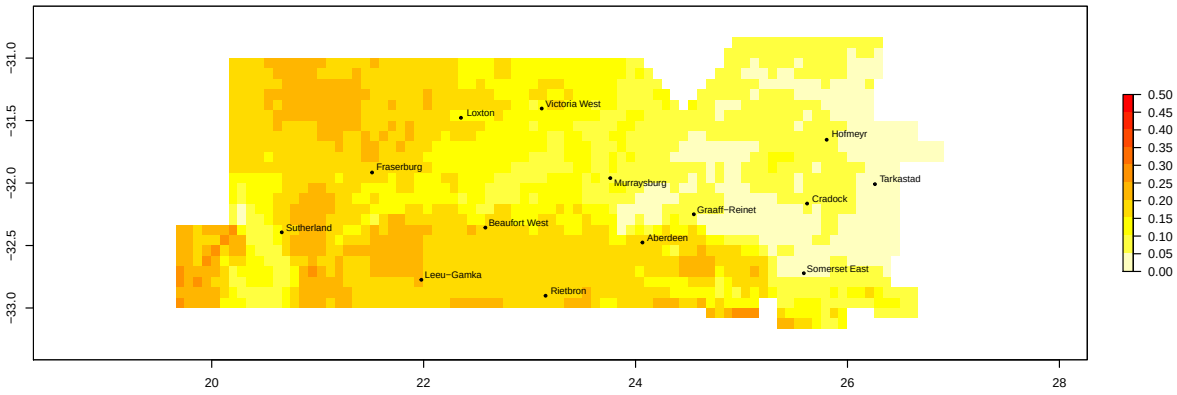
Uroplectes carinatus



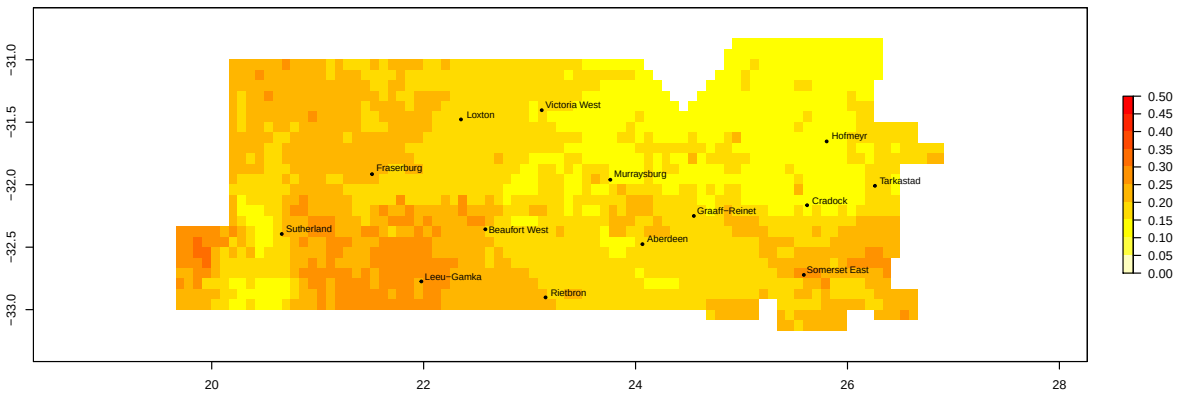
Uroplectes formosus

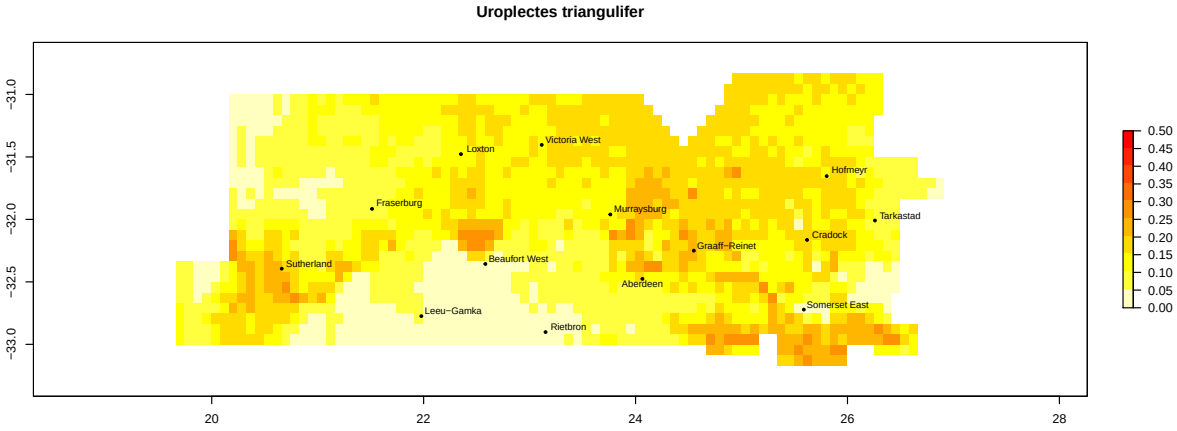


Uroplectes gracilior



Uroplectes schlechteri




Uroplectes triangulifer
−31.0
−31.5
−32.0
−32.5
−33.0
20
22
24
26
28
Loxton
Victoria West
Hofmeyr
Fraserburg
Murraysburg
Tarkastad
Cradock
Graaff−Reinet
Sutherland
Beaufort West
Aberdeen
Somerset East
Leeu−Gamka
Rietbron
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00

6 Appendices

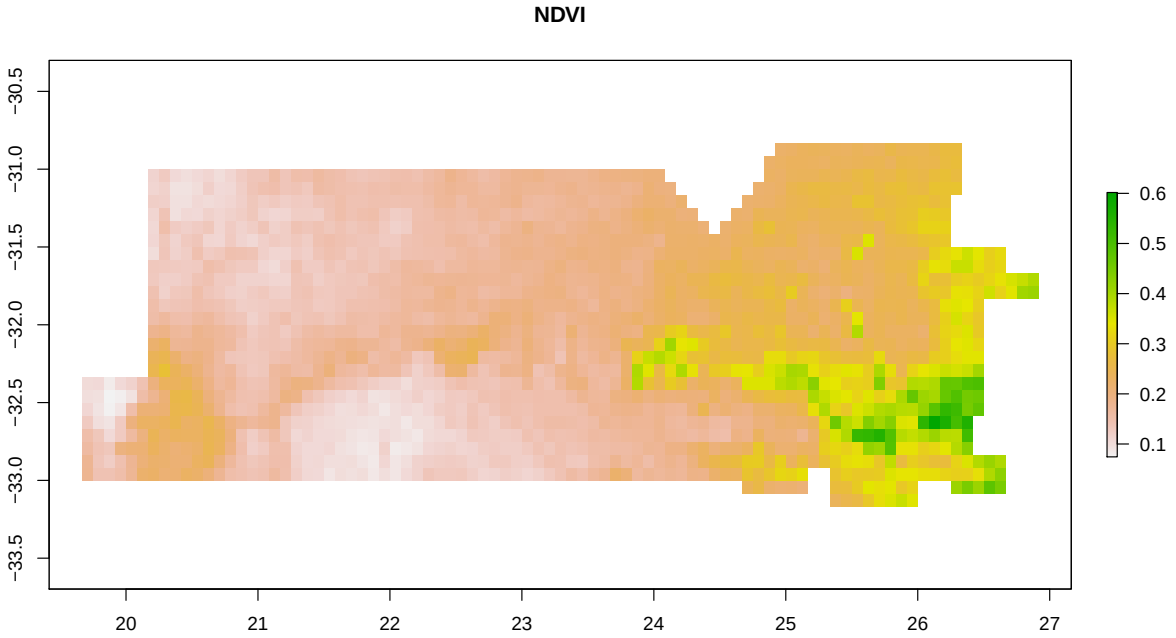
6.1 Appendix A - Species list

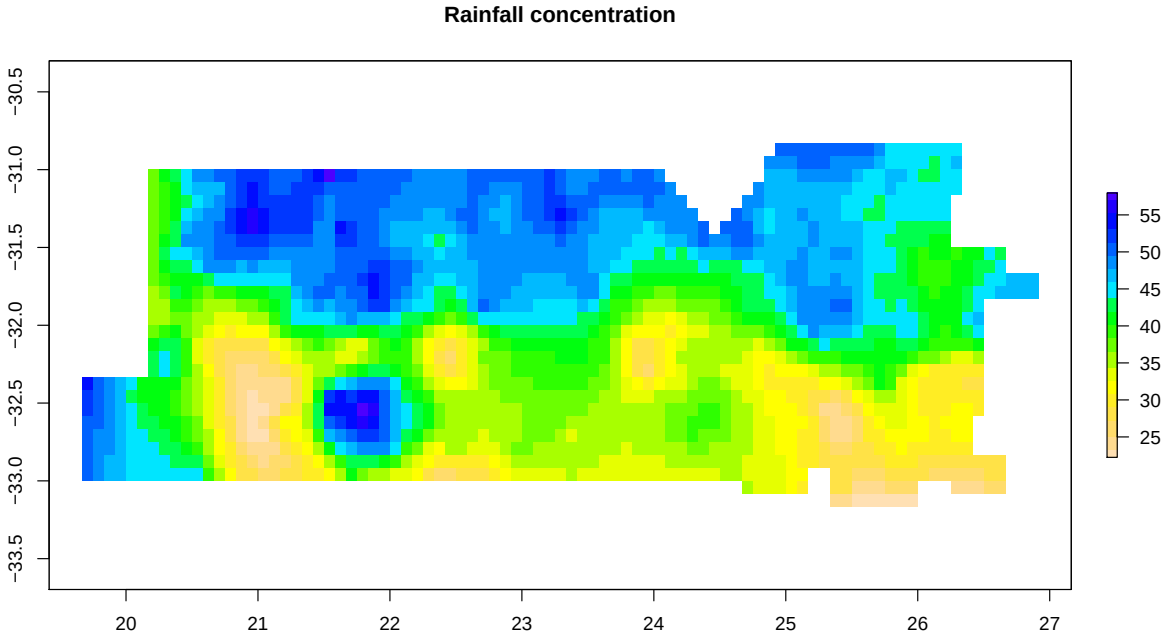
List of scorpion species recorded during the fieldwork surveys.

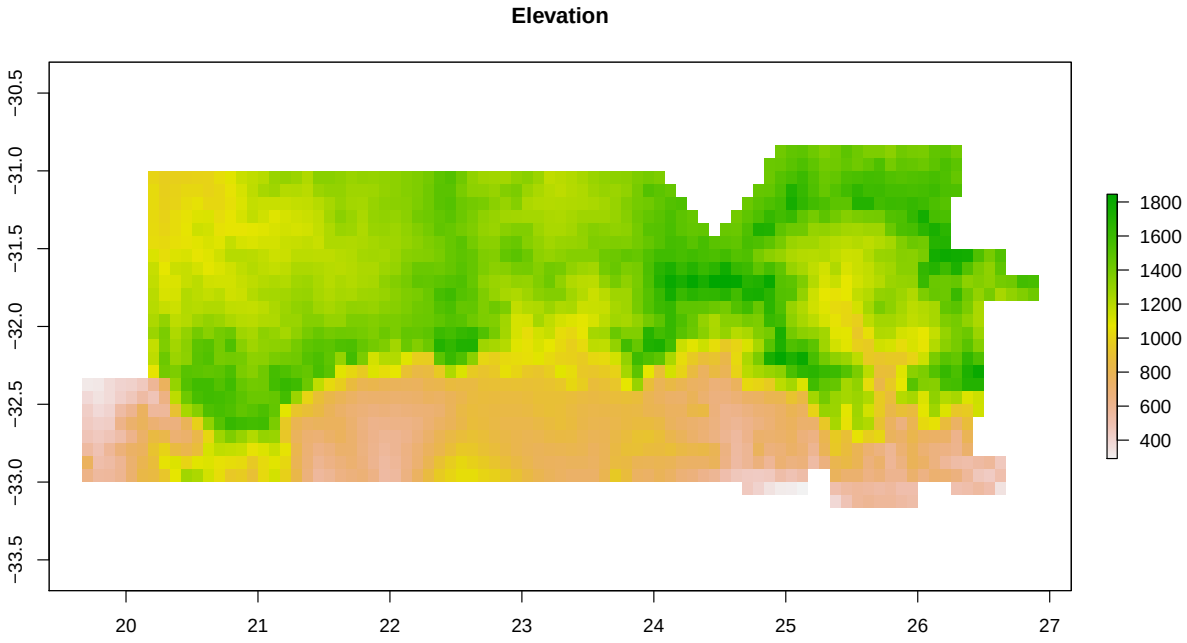
Species
Hadogenes sp.
Hadogenes trichiurus
Opisthacanthus validus
Opistophthalmus austeroides
Opistophthalmus austerus
Opistophthalmus crassimanus
Opistophthalmus karrooensis
Opistophthalmus laticauda
Opistophthalmus latimanus
Opistophthalmus lornae
Opistophthalmus nitidiceps
Opistophthalmus pallipes
Opistophthalmus pictus
Opistophthalmus sp.
Parabuthus capensis
Parabuthus granulatus
Parabuthus nanus
Parabuthus planicauda
Parabuthus schlechteri
Uroplectes ansiedippenaarae
Uroplectes carinatus
Uroplectes formosus
Uroplectes gracilior
Uroplectes schlechteri
Uroplectes triangulifer

6.2 Appendix B - Covariate maps

Maps of environmental covariates across the BioGaps study area.



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−31.5
−32.0
−32.5
−33.0
−33.5
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21
22
23
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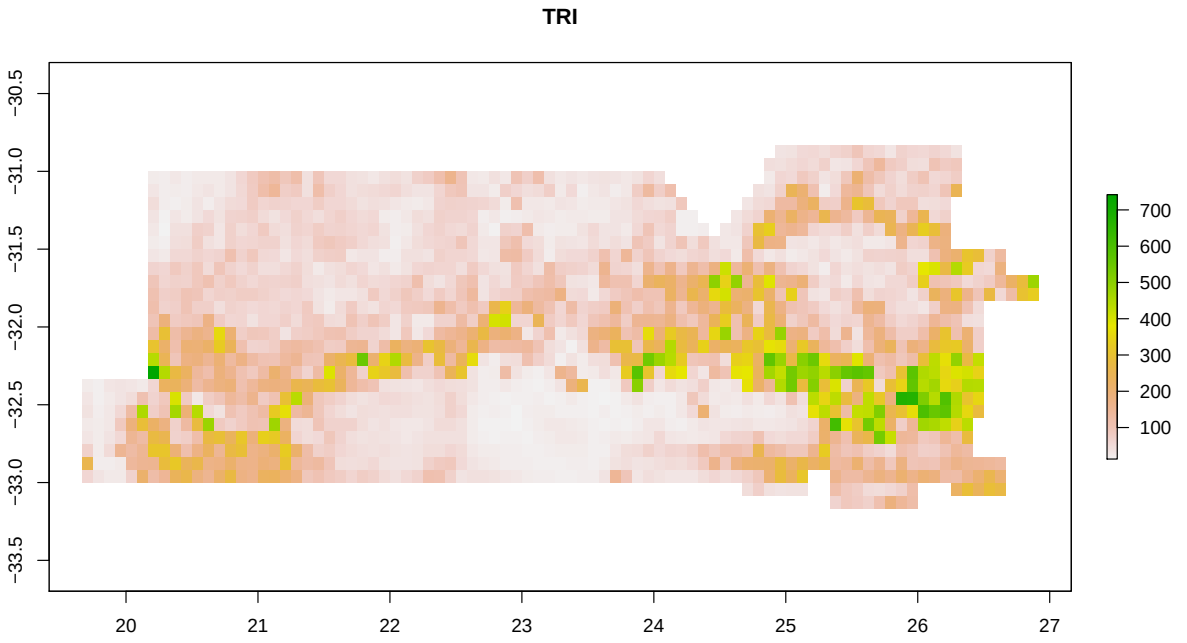
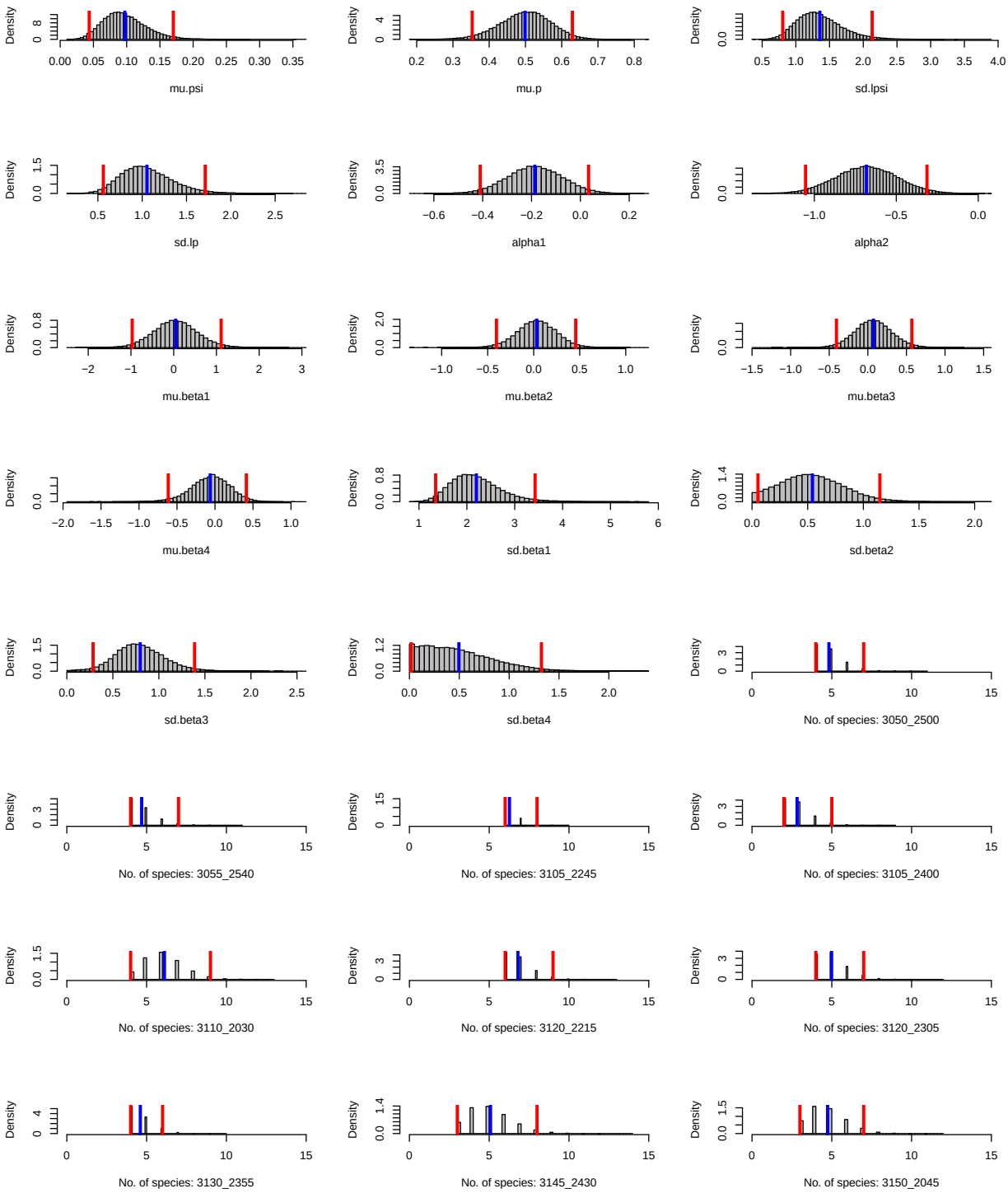
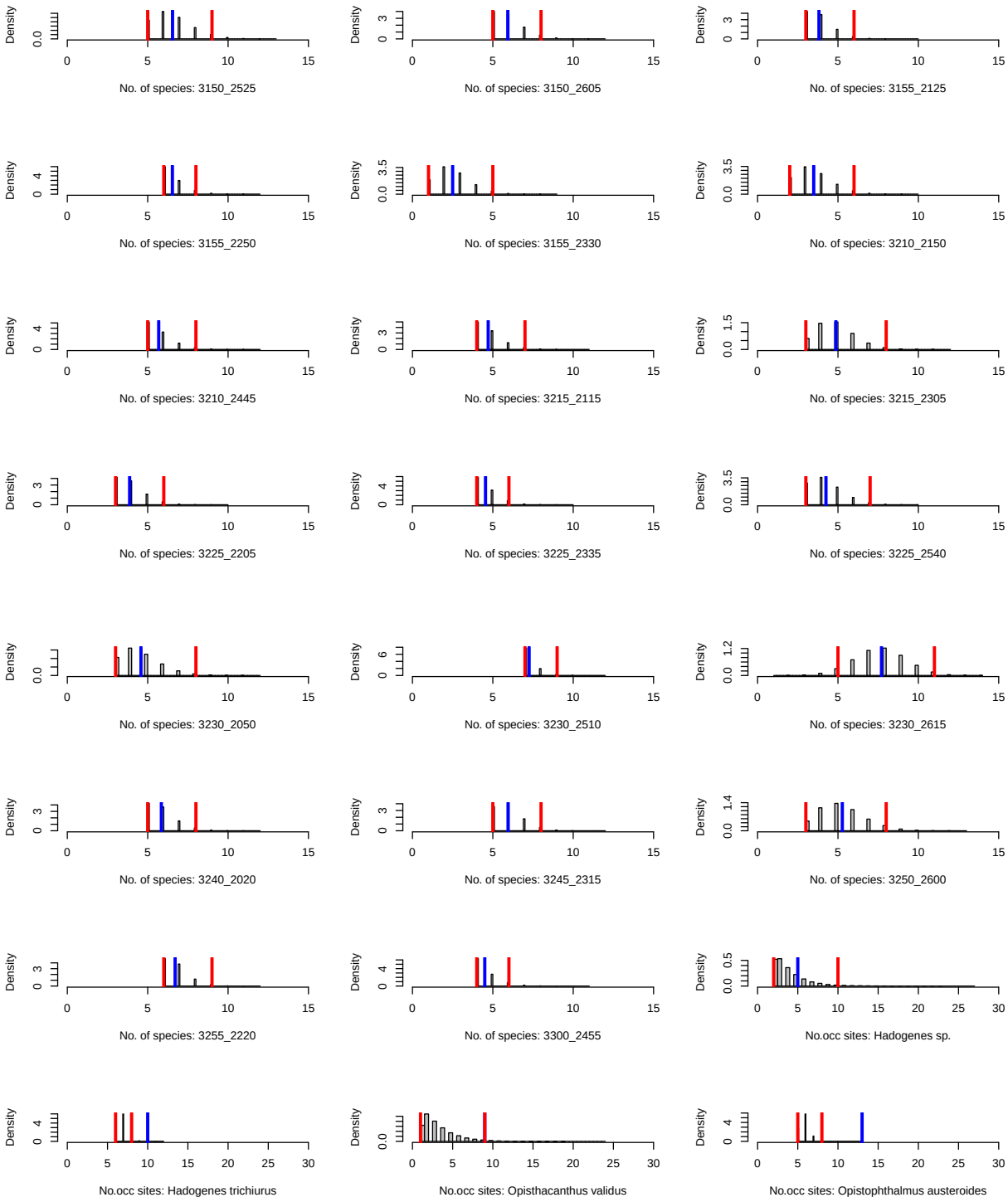
26
27
1800
1600
1400
1200
1000
800
600
400


TRI
−30.5
−31.0
−31.5
−32.0
−32.5
−33.0
−33.5
20
21
22
23
24
25
26
27
700
600
500
400
300
200
100

6.3 Appendix C - Model diagnostics

These plots show the posterior distribution of each derived model parameter. Following these are traceplots show R-hat values and diagnostics of parameter convergence. **Add explanation/key about parameter names**

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No. of species: 3150_2605
No. of species: 3155_2125
No. of species: 3155_2250
No. of species: 3155_2330
No. of species: 3210_2150
No. of species: 3210_2445
No. of species: 3215_2115
No. of species: 3215_2305
No. of species: 3225_2205
No. of species: 3225_2335
No. of species: 3225_2540
No. of species: 3230_2050
No. of species: 3230_2510
No. of species: 3230_2615
No. of species: 3240_2020
No. of species: 3245_2315
No. of species: 3250_2600
No. of species: 3255_2220
No. of species: 3300_2455
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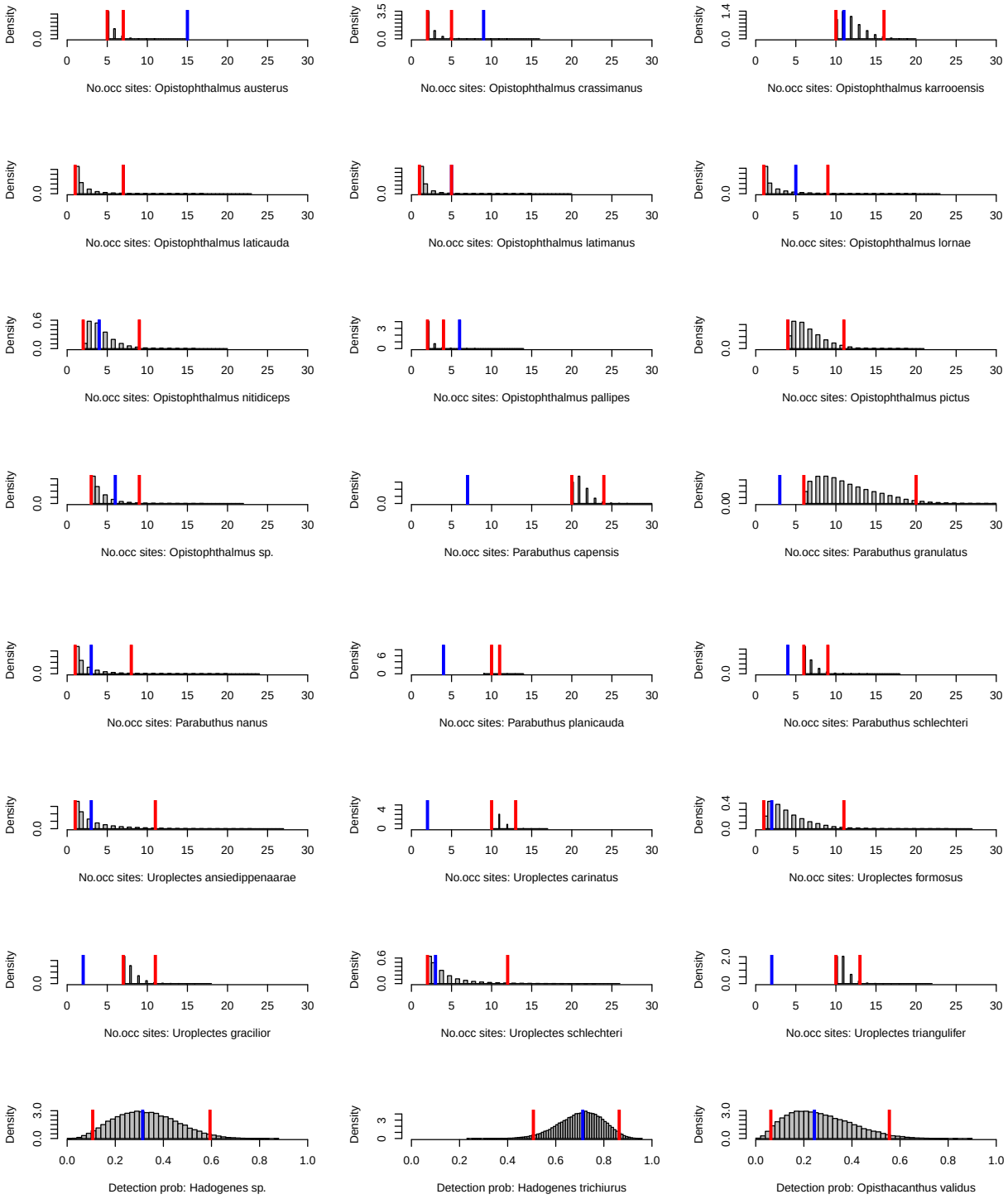
No.occ sites: Hadogenes trichiurus
No.occ sites: Opisthacanthus validus
No.occ sites: Opistophthalmus austeroides


Density
No.occ sites: Opistophthalmus austerus
No.occ sites: Opistophthalmus crassimanus
No.occ sites: Opistophthalmus karrooensis
No.occ sites: Opistophthalmus laticauda
No.occ sites: Opistophthalmus latimanus
No.occ sites: Opistophthalmus lornae
No.occ sites: Opistophthalmus nitidiceps
No.occ sites: Opistophthalmus pallipes
No.occ sites: Opistophthalmus pictus
No.occ sites: Opistophthalmus sp.
No.occ sites: Parabuthus capensis
No.occ sites: Parabuthus granulatus
No.occ sites: Parabuthus nanus
No.occ sites: Parabuthus planicauda
No.occ sites: Parabuthus schlechteri
No.occ sites: Uroplectes ansiedippenaarae
No.occ sites: Uroplectes carinatus
No.occ sites: Uroplectes formosus
No.occ sites: Uroplectes gracilior
No.occ sites: Uroplectes schlechteri
No.occ sites: Uroplectes triangulifer
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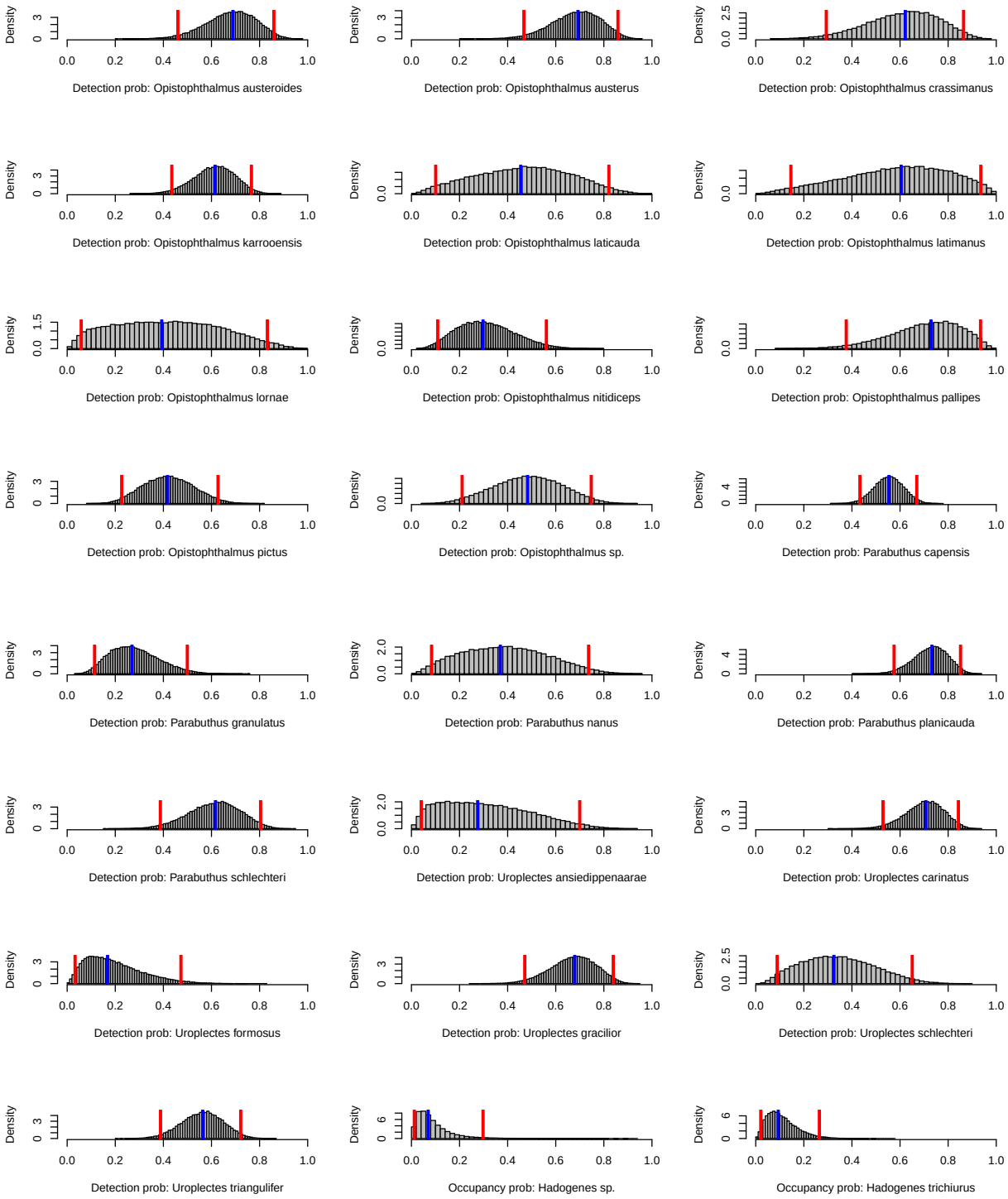
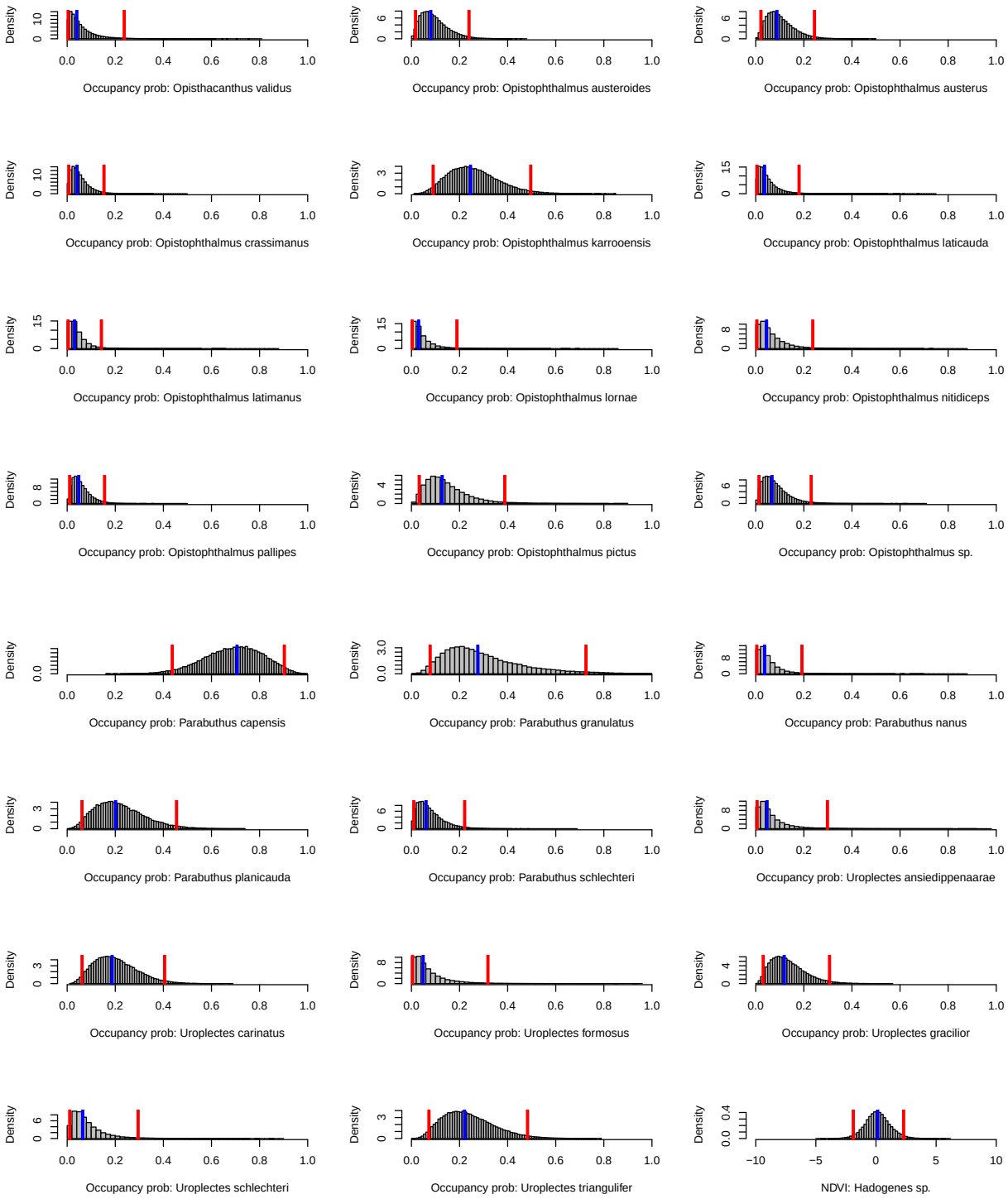
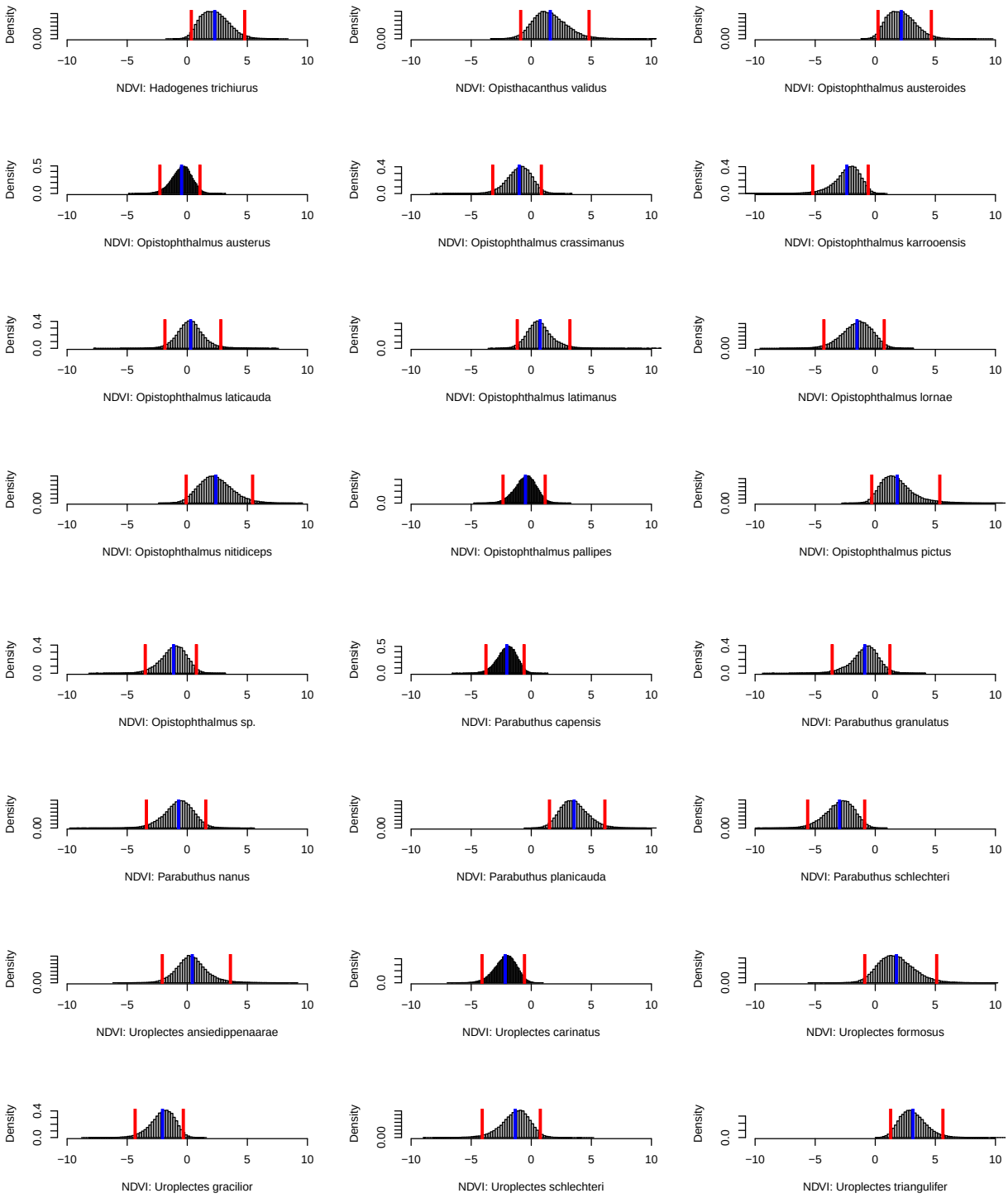
Detection prob: Hadogenes trichiurus
Detection prob: Opisthacanthus validus


Density
Detection prob: Opistophthalmus austeroides
Detection prob: Opistophthalmus austerus
Detection prob: Opistophthalmus crassimanus
Detection prob: Opistophthalmus karrooensis
Detection prob: Opistophthalmus laticauda
Detection prob: Opistophthalmus latimanus
Detection prob: Opistophthalmus lornae
Detection prob: Opistophthalmus nitidiceps
Detection prob: Opistophthalmus pallipes
Detection prob: Opistophthalmus pictus
Detection prob: Opistophthalmus sp.
Detection prob: Parabuthus capensis
Detection prob: Parabuthus granulatus
Detection prob: Parabuthus nanus
Detection prob: Parabuthus planicauda
Detection prob: Parabuthus schlechteri
Detection prob: Uroplectes ansiedippenaarae
Detection prob: Uroplectes carinatus
Detection prob: Uroplectes formosus
Detection prob: Uroplectes gracilior
Detection prob: Uroplectes schlechteri
Detection prob: Uroplectes triangulifer
Occupancy prob: Hadogenes sp.
Occupancy prob: Hadogenes trichiurus


Density
Occupancy prob: Opisthacanthus validus
Occupancy prob: Opistophthalmus austeroides
Occupancy prob: Opistophthalmus austerus
Occupancy prob: Opistophthalmus crassimanus
Occupancy prob: Opistophthalmus karrooensis
Occupancy prob: Opistophthalmus laticauda
Occupancy prob: Opistophthalmus latimanus
Occupancy prob: Opistophthalmus lornae
Occupancy prob: Opistophthalmus nitidiceps
Occupancy prob: Opistophthalmus pallipes
Occupancy prob: Opistophthalmus pictus
Occupancy prob: Opistophthalmus sp.
Occupancy prob: Parabuthus capensis
Occupancy prob: Parabuthus granulatus
Occupancy prob: Parabuthus nanus
Occupancy prob: Parabuthus planicauda
Occupancy prob: Parabuthus schlechteri
Occupancy prob: Uroplectes ansiedippenaarae
Occupancy prob: Uroplectes carinatus
Occupancy prob: Uroplectes formosus
Occupancy prob: Uroplectes gracilior
Occupancy prob: Uroplectes schlechteri
Occupancy prob: Uroplectes triangulifer
NDVI: Hadogenes sp.


Density
NDVI: Hadogenes trichiurus
NDVI: Opisthacanthus validus
NDVI: Opistophthalmus austeroides
NDVI: Opistophthalmus austerus
NDVI: Opistophthalmus crassimanus
NDVI: Opistophthalmus karrooensis
NDVI: Opistophthalmus laticauda
NDVI: Opistophthalmus latimanus
NDVI: Opistophthalmus lornae
NDVI: Opistophthalmus nitidiceps
NDVI: Opistophthalmus pallipes
NDVI: Opistophthalmus pictus
NDVI: Opistophthalmus sp.
NDVI: Parabuthus capensis
NDVI: Parabuthus granulatus
NDVI: Parabuthus nanus
NDVI: Parabuthus planicauda
NDVI: Parabuthus schlechteri
NDVI: Uroplectes ansiedippenaarae
NDVI: Uroplectes carinatus
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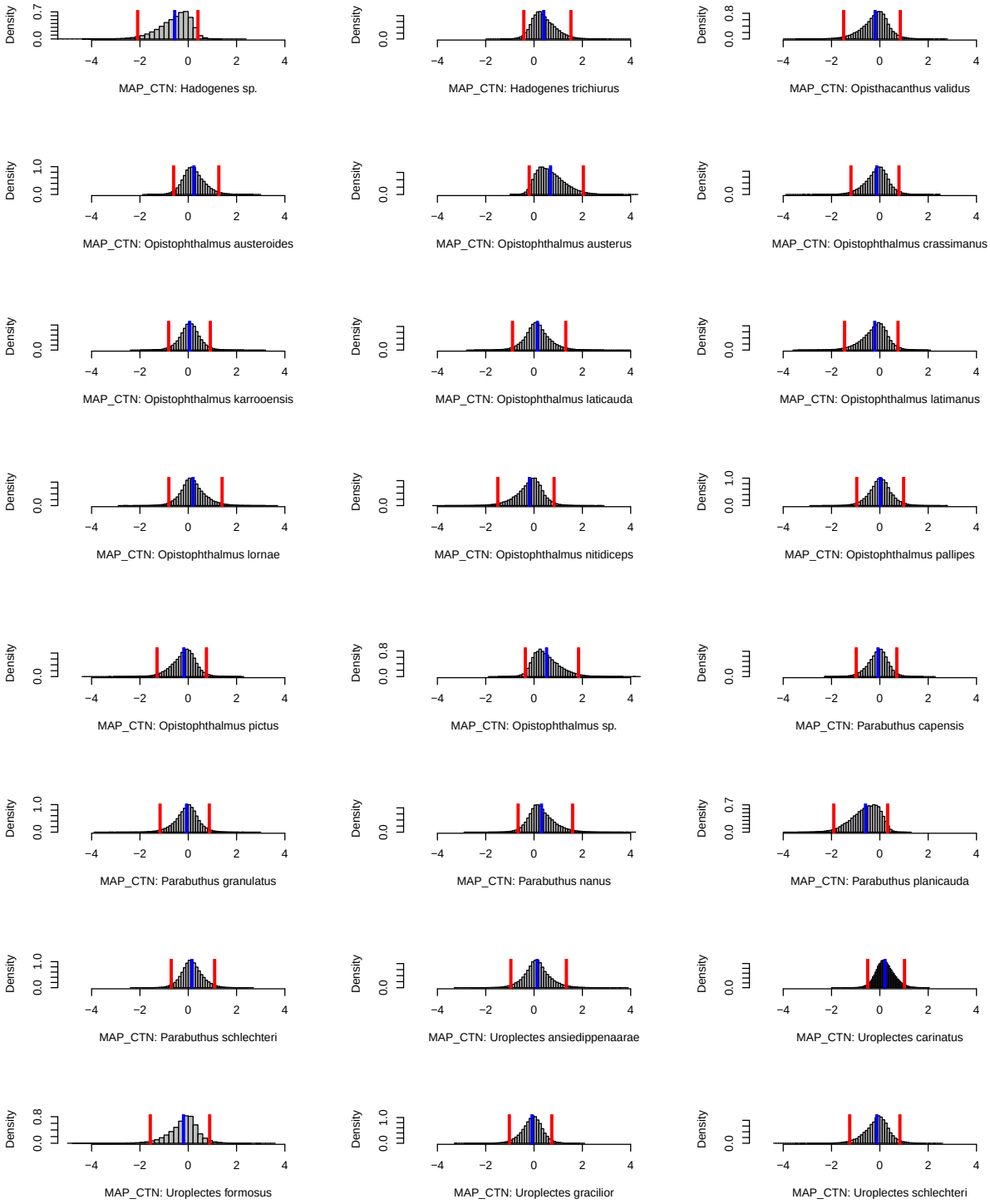
NDVI: Uroplectes triangulifer


Density
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MAP_CTN: Hadogenes trichiurus
MAP_CTN: Opisthacanthus validus
MAP_CTN: Opistophthalmus austeroides
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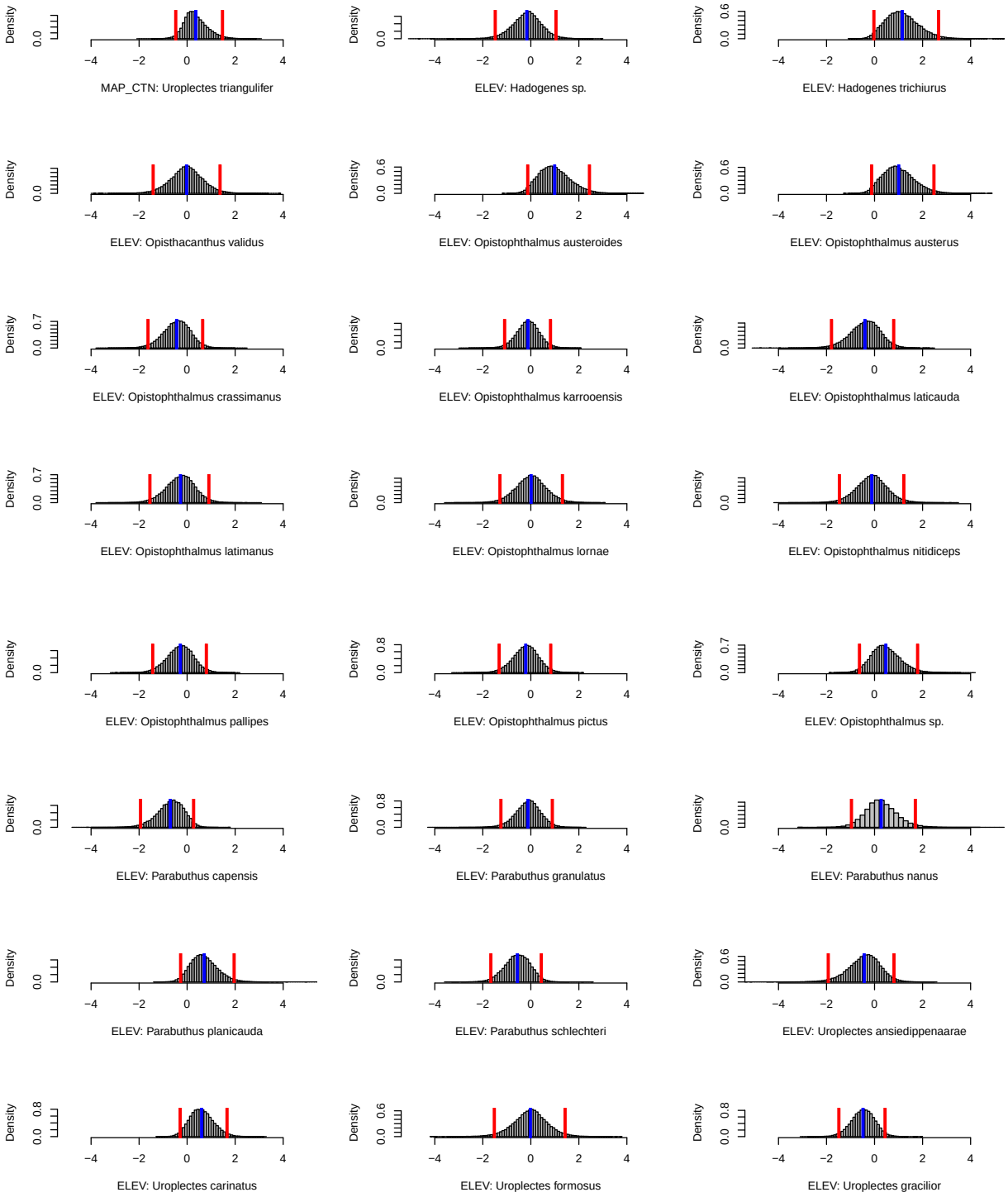
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ELEV: Opistophthalmus crassimanus
ELEV: Opistophthalmus karrooensis
ELEV: Opistophthalmus laticauda
ELEV: Opistophthalmus latimanus
ELEV: Opistophthalmus lornae
ELEV: Opistophthalmus nitidiceps
ELEV: Opistophthalmus pallipes
ELEV: Opistophthalmus pictus
ELEV: Opistophthalmus sp.
ELEV: Parabuthus capensis
ELEV: Parabuthus granulatus
ELEV: Parabuthus nanus
ELEV: Parabuthus planicauda
ELEV: Parabuthus schlechteri
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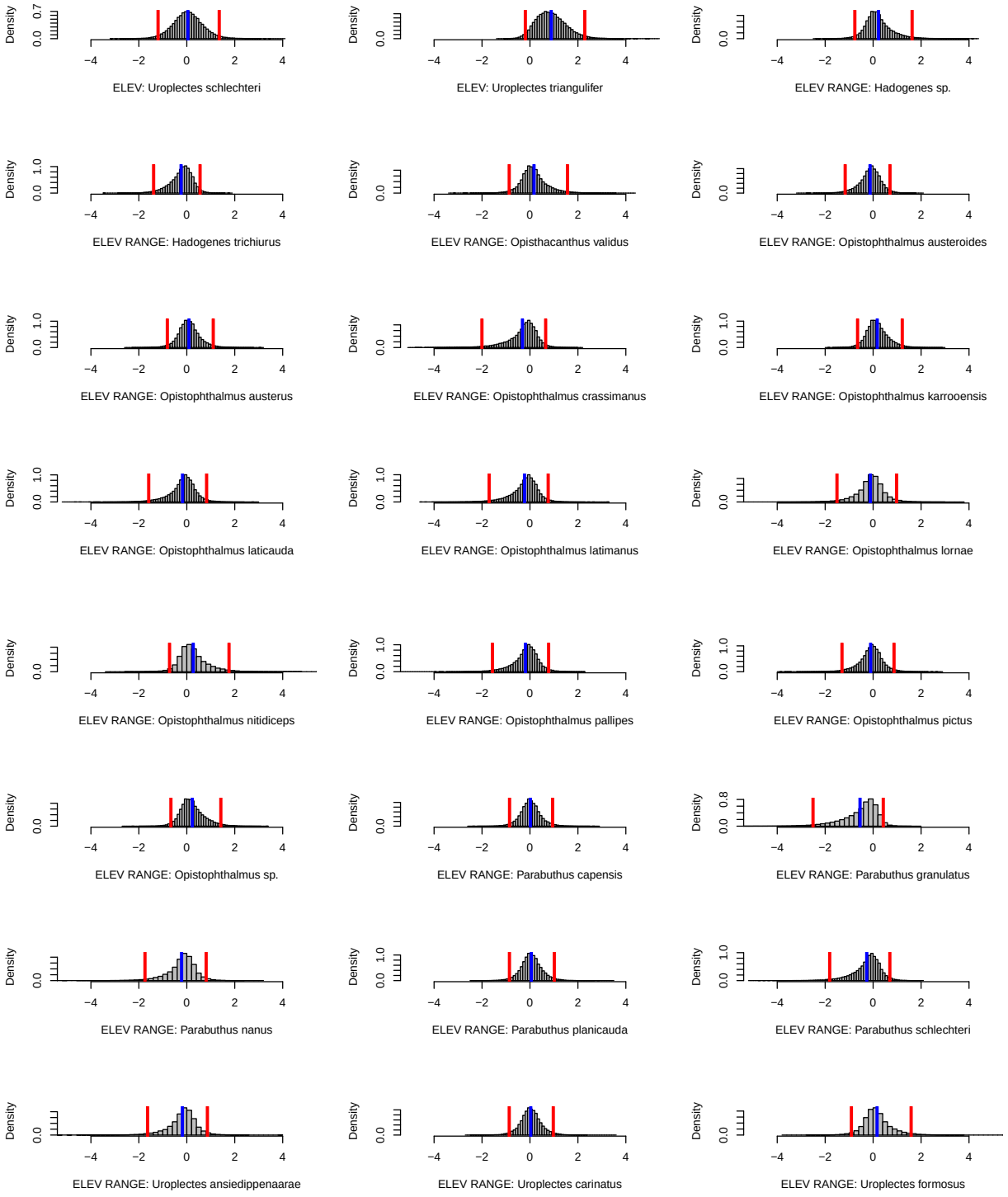
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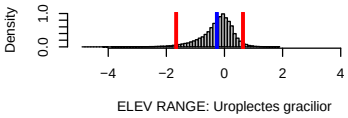
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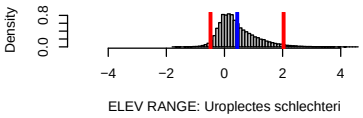
ELEV RANGE: Uroplectes gracilior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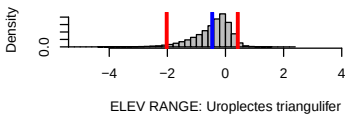
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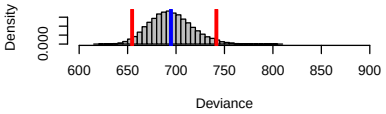
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