Ecography

E7749
Haby, N. A., Prowse, T. A. A., Gregory, S. D., Watts, M. J., Delean, S., Fordham, D. A., Foulkes, J. and Brook, B. W. 2012. Scale dependency of metapopulation models used to predict climate change impacts on small mammals. – Ecography 35: xxx–xxx.

Supplementary material

Appendix 1

Spatial landscape variables used. Some variables shared some correlation (r > 0.6), including between MT and RS (-0.60), RS and RW (0.77), RS and E (0.78), RW and E (0.82), RW and H (0.64). Variable range was similar between resolutions, however, marked differences occurred in the spatial arrangement of higher resolution vectors layers (resolution ~25 x 25 m), resampled to 1 x 1 km resolution.

Variable	**Description**	**Native resolution**	**Range (min-max)**	**Source**
Climate				
MT	Ave. monthly minimum temperature	1 x 1 km	4.3 - 9.7 ^{o}C	Baseline climate layers were created from meteorological station data (Australian Bureau of Meterology), combined with elevation from a 250 m DEM (Geoscience Australia 2008) and interpolated across the region using thin plate smoothing splines in ANUSPLIN to a 1 km resolution (Hutchinson 2006, Fordham et al. 2011). These were used to generate the initial SDMs. An ensemble of the top ranking global climate models (GCM) in Australia was then used to predict future climate using parameters from several climate change scenarios. A period of 40 years from the no-policy-change 'reference' scenario (Fordham et al. 2011) was extracted for this investigation.
RS	Ave. monthly summer rainfall (Nov - Jan)	1 x 1 km	13.9 - 31.2 mm	
RW	Ave. monthly winter rainfall (Jun - Aug)	1 x 1 km	0.01 km^2: 41.4 - 132.4 mm 1.0 km^2: 50.4 - 132.4 mm	
Topography				
E	Elevation	27x 27 m	0.01 km^2: 0 - 690 m 1.0 km^2: -1 - 648 m	Elevation and slope were derived from a 25 m DEM and the distance from the nearest watercourse from available watercourse and body vector information (Department for Environment and Natural Resources, DENR), using ArcGIS 9.2 (ESRI 2009). Values were transformed using the natural log.
lnWC	Distance from nearest water course or body	21 x 21 m	2.9 - 9.5	
Soil and vegetation				
M	Root zone water holding capacity	25 x 25 m	0, 1	Soil vector data were available from PIRSA (2001) and vegetation vector data from DENR. Categorical root zone water holding capacity values were reclassified to 1 where > 50% area within a mapped polygon had high root zone water holding capacity, and 0 for polygons where > 50% area had moderate to very low water holding capacity. Categorical soil acidity data were reclassified to 1 where polygons contained > 20% acidic surface and sub-surface soil cover, and 0 where > 20% of the area, neutral of alkaline soils. Vegetation communities > 15 ha were mapped from 1: 40 000 aerial photographs (1987), with assistance from the classification of structural and floristic data (Foulkes and Heard 2003). Categorical data were reclassified as 1, sedgeland, fernland or grassland; 2, woodland or mallee woodland; 3 forest or mallee forest; 4 shrubland.
H	Soil acidity	25 x 25 m	0, 1	
GEN	Broad vegetation community	25 x 25 m	0, 1, 2, 3, 4	

Foulkes, J. and Heard, L. 2003. A biological survey of the South East, South Australia, 1991 and 1997. – Dept for Environment and Heritage, South Australia.

Hutchinson, M. 2006. Anusplin version 4.36. – Centre for Resource and Environmental Studies, The Australian National Univ., Canberra.

Appendix 2

Evaluation of species distribution models.

Regardless of the spatial scale employed, SDMs better explained the occupancy of the more mobile woodland generalist and insectivore (*A. f. flavipes*), compared to the wet-heath specialist (*R. l. lutreolus*), and two understorey preferring species (*I. o. obesulus* and *R. f. greyi*) (50.1 - 25.6% DE; Table 2a). Rainfall parameters were the most important predictors of species distribution in all cases. Distance to watercourse and root zone water holding capacity were also important predictors of *R. l. lutreolus* and *A. f. flavipes* occurrence (Appendix 2b). Elevation, soil acidity and average minimum temperature during summer were most strongly correlated with the occurrence of the insectivore *A. f. flavipes* and omnivore *I. o. obesulus*.

A suitable threshold to convert probability values into suitable and unsuitable habitat was determined by comparing the predicted probability with the actual occurrence of the model data. As all data were used, validation statistics provide an optimistic indication of the 'best case' performance of these models may be obtained when used to predict the original species occurrence. These models predictive performances were relatively good (AUC values: 0.82-0.94 Kappa values: 0.53-0.66; Table 2a), which were lower than expected probably as a result of small datasets.

Table A1. Explanatory strength of null and *a priori* generalised linear models constructed using a) 0.01 km^2, and b) 1.0 km^2 resolution environmental data. Shown are the number of parameters (*k*), minimised negative log-likelihood (-LL) and the per cent deviance explained by the model relative to the null (% DE) for each species. Also shown is validation statistics derived from the model being predicted back onto the original dataset. These statistics include the area under the curve (AUC) and when the Maximum Sensitivity and Specificity threshold is used to convert the probability of occurrence into present, or absent, the Kappa, Sensitivity (Sens) and Specificity (Spec). Note: Where the resampling of environmental data caused missing values for presence records, values were manually substituted from the original environmental data layers.

Species	**Model variables**	***k***	**-LL**	**% DE**	**AUC (SD)**	**Kappa (SD)**	**Sens (SD)**	**Spec (SD)**
a. 0.01 km^2								
I. o. obesulus	~ MT+RS+RW+E+lWC+H+GEN	10	-279.0	30.6	0.85 (0.02)	0.53 (0.04)	0.76 (0.03)	0.79 (0.02)
A. f. flavipes	~ MT+RS+RW+E+lWC+M+H+GEN	11	-109.8	48.8	0.93 (0.01)	0.60 (0.04)	0.93 (0.03)	0.84 (0.02)
R. f. greyi	~ MT+RS+RW+E+lWC+GEN	9	-257.1	27.7	0.83 (0.02)	0.58 (0.04)	0.64 (0.03)	0.92 (0.02)
R. l. lutreolus	~ RS+E+lWC+GEN+M+H	9	-89.5	46.3	0.94 (0.01)	0.61[a] (0.05)	0.79[a] (0.06)	0.93[a] (0.01)
b. 1.0 km^2								
I. o. obesulus	~ MT+RS+RW+E+lWC+H+GEN	10	-245.3	30.6	0.85 (0.02)	0.56 (0.04)	0.78 (0.03)	0.79 (0.02)
A. f. flavipes	~ MT+RS+RW+E+lWC+M+H+GEN	11	-96.8	50.1	0.93 (0.02)	0.66 (0.04)	0.95 (0.02)	0.84 (0.02)
R. f. greyi	~ MT+RS+RW+E+lWC+GEN	9	-230.2	25.6	0.82 (0.02)	0.57 (0.04)	0.64 (0.03)	0.91 (0.02)
R. l. lutreolus	~ RS+E+lWC+GEN+M+H	9	-85.9	43.9	0.94 (0.01)	0.62[a] (0.06)	0.75[a] (0.06)	0.93[a] (0.01)

[a] Derived using a threshold to maximise the Kappa statistic (MaxKappa) due to the very low prevalence of presence records.

Table A2. Explanatory strength of each variable calculated using generalised linear modelling (GLM), derived by combining the % deviance explained when a variable is deleted from the saturated model with the % deviance explained when adding that variable to the null model, divided by the number of degrees of freedom (as per Garnett and Brook 2007). Note: Where the resampling of environmental data caused missing values for presence records, values were manually substituted from the original environmental data layers.

		I. o. obesulus		*A. f. flavipes*		*R. f. greyi*		*R. l. lutreolus*	
Variable	df	km^2:0.01	1.0	0.01	1.0	0.01	1.0	0.01	1.0
MT	1	3.9	4.2	5.7	8.0	0.5	0.3		
RS	1	17.8	19.7	32.0	35.5	15.1	15.9	23.4	24.9
RW	1	26.2	26.8	34.2	34.5	26.7	25.6		
E	1	14.0	14.7	25.2	25.9	3.2	3.4	6.2	5.2
lnWC	1	5.4	4.1	8.6	10.9	3.1	4.0	20.8	12.5
M	1			10.1	12.3			17.3	14.2
H	1	11.5	10.5	11.2	15.1			2.6	1.8
GEN	3	1.3	1.4	3.0	2.1	0.6	0.4	7.4	9.1

MT, average minimum temperature in winter (Jun - Aug); RS / RW, average monthly rainfall during summer (Nov-Jan) and winter; E, elevation; lnWC, distance from nearest water course or body transformed using the natural logarithm; M, root zone water holding capacity; H, soil acidity; GEN, broad vegetation community.

Appendix 3

Change in distribution and extent of available habitat, number of populations and species abundance predicted over 40 years of climate change, over 1000 iterations, for the species' range on the a) Fleurieu Peninsula and b) South East. No changes in the parameters below were reported over the burn-in period.

	I. o. obesulus		*A. f. flavipes*		*R. f. greyi*		*R. l. lutreolus*	
Resolution (km^2)	0.01	1.0	0.01	1.0	0.01	1.0	0.01	1.0
a. Fleurieu Peninsula								
Initial area of habitat (km^2)	198	221	317	306	227	255	28	15
Initial no. patches	1182	82	1292	113	947	76	1069	15
Ave. initial no. populations (SD)[1]	1011	82	1198	113	935	76	626	15
	(0.0)	(0.03)	(0.0)	(0.1)	(0.0)	(0.06)	(0.0)	(0.0)
Max no. patches within dispersal dist.	35	0	137	0	47	0	8	0
and when Dmax = 5 km (SA1 and 3)	168	11	323	14	156	11	96	3
Changes following 40 years of climate change:								
Habitat area (%)	-74	-60	-37	-3	-94	-86	-62	-40
Population no. (%)	-65	-52	-15	-4	-87	-69	-9	-22
No. new populations created	748	14	1095	21	975	22	157	1
Ave. abund. animals yr^{-1} (SE)	-694	-3523	-135	-4364	-4364	-6538	-123	-508
	(37)	(1481)	(28)	(124)	(124)	(1693)	(7)	(58)
r^2 (p value)	0.90**	0.74**	0.37**	0.14	0.97**	0.96**	0.89**	0.93**
No. occupied popns yr^{-1} (SE)	-13.4	-0.8	-1.3	-0.1	-19.7	-1.5	-2.3	-0.1
	(1.0)	(0.1)	(0.7)	(0.0)	(0.7)	(0.1)	(0.3)	(0.0)
r^2 (p value)	0.80**	0.74**	0.08	0.14	0.96**	0.96**	0.56**	0.93**
Expected minimum abundance (%)	24	40	58	85	8	14	57	57
b. South East								
Initial area of habitat (km^2)	82	92	66	101	212	269	523	514
Initial no. patches	260	34	237	49	613	91	2567	217
Ave. initial no. populations (SD)[1]	223	34	213.4	49	604.9	91	2108	217
	(2.18)	(0)	(1.1)	(0.1)	(0)	(0.1)	(0)	(0)
Max no. patches within dispersal dist.	13	0	13	0	28	0	15	0
and when Dmax = 5 km (SA1 and 3)	42	4	35	5	102	10	99	9
Changes following 40 years of climate change:								
Habitat area (%)	-35	-15	-24	2	-61	-40	-20	-10
Population no. (%)	-21	-15	-20	0	-56	-47	-3	3
No. new populations created	74	1	162	10	255	5	180	16
Ave. abund. animals yr^{-1} (SE)	-223	-89	-97	14	-2052	-2742	-1217	-400
	(22)	(7)	(13)	(4)	(58)	(48)	(113)	(76)
r^2 (p value)	0.73**	0.80**	0.58**	0.28**	0.97*	0.99**	0.77**	0.45**
No. occupied popns yr^{-1} (SE)	-1.5	-0.1	-1.4	-0.0	-11.3	-1.2	-4.3	0.12
	(0.1)	(0.0)	(0.2)	(0.0)	(0.6)	(0.0)	(0.9)	(0.03)
r^2 (p value)	0.75**	0.61**	0.65**	0.10*	0.91**	0.99**	0.38**	0.30**
Expected minimum abundance (%)	65	80	68	89	44	56	78	88

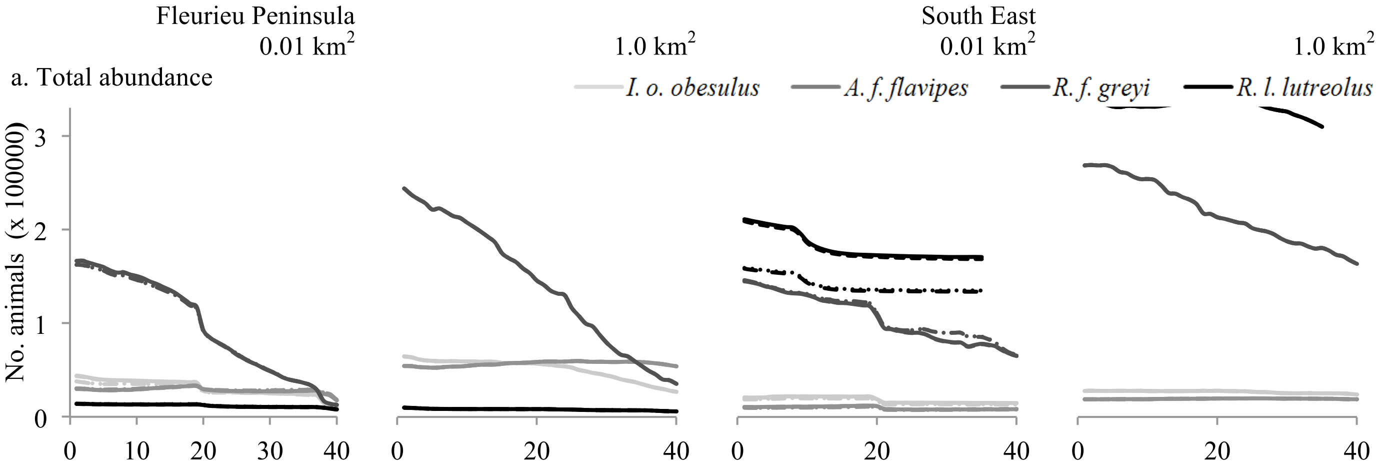
[1] Average number of populations at the last time step of the 20 years of stable climate from 1000 iterations

*p value < 0.05, ** p value < 0.001

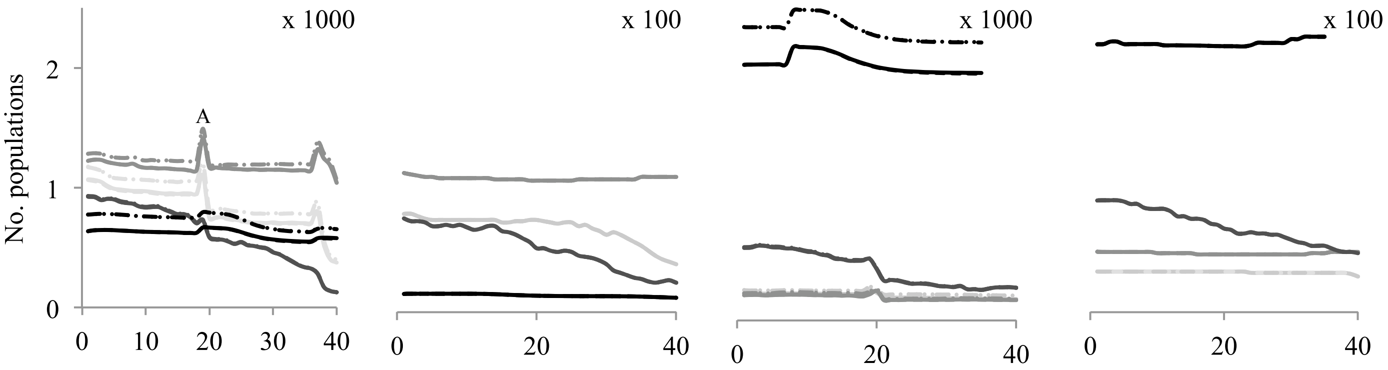
[a] Negative values indicate an overall range expansion, rather than contraction

Appendix 4

a. Total abundance

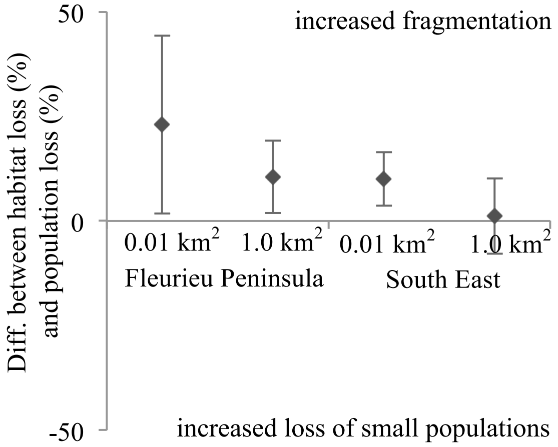


b. Number of populations



Total number of animals (a) and populations (b) over 40 years of simulated climate change, represented at two scales of resolution (0.01 and 1.0 km^2). Results for the sensitivity analyses are also shown, including increasing potential habitat connectivity by increasing max dispersal to 5 km given environmental data are limited (SA1, dotted line), increasing the SD of mortality to 10% (SA2, square dotted line), and a combination of both (SA3, dashed line). Temporary peaks (e.g. A) indicate time steps where habitat suitability of many pixels falls below threshold, leading to a substantial alteration in the area and spatial configuration of available habitat and increase in translocated populations that perish in the subsequent time step.

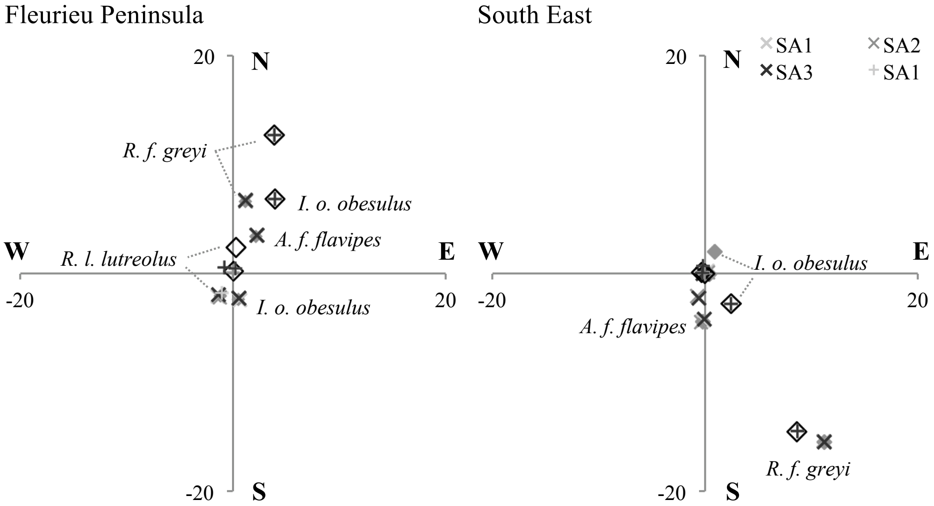
Appendix 5



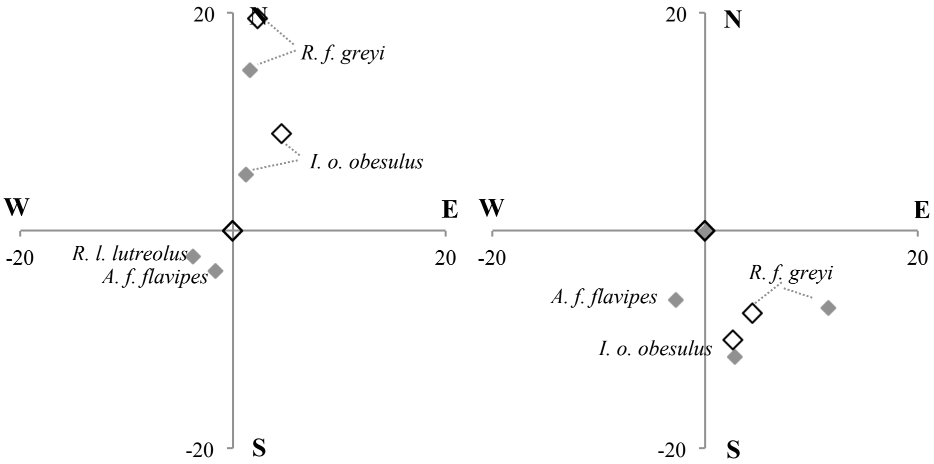
Test for bias in loss of small populations (decline in number of populations > decline in available habitat). A greater loss of small populations at the fine-scale is not evident. Instead, there was a greater loss in available habitat (%) than number of populations (%) indicating increased habitat fragmentation is shown across all scales and regions.

Appendix 6

a. Occupied habitat



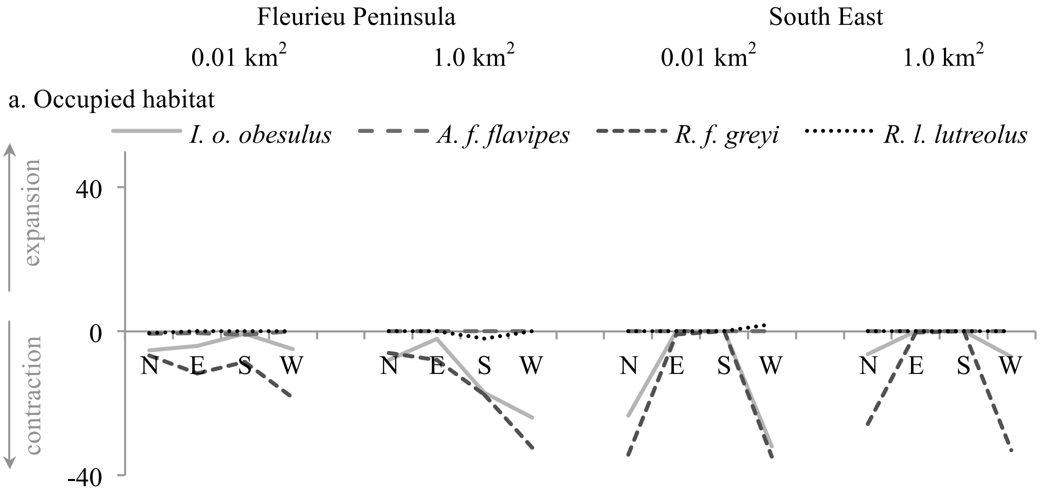
b. Available habitat



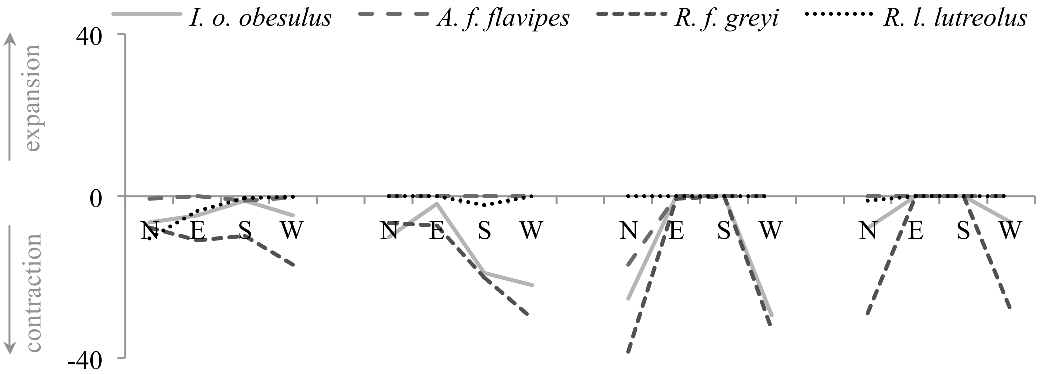
Shift in the centre-point of occupied (a) and available (b) habitat at 0.01 and 1.0 km^2 resolution (solid or hollow symbols, respectively), in the Fleurieu Peninsula and South East. The centre points calculated during each of the sensitivity analyses performed on the metapopulation model are also shown, included increasing potential habitat connectivity by increasing maximum dispersal to 5 km given environmental data are limited (SA1, light grey), increasing the SD of mortality to 10% (SA2, medium grey), and a combination of both (SA3, dark grey).

Appendix 7

a. Occupied habitat



b. Available habitat



Contractions in the extent of occupied (a) and available (b) habitat at 0.01 km^2 and 1.0 km^2 resolution, within the Fleurieu Peninsula, and South East. In the South East, expansion in the south-easterly direction is constrained by the coast (south) and this investigation being constrained by a state boundary (east).