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Wildlife Research

Supplementary Material

Using expert elicitation to identify effective combinations of management actions for koala conservation in different regional landscapes

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Supplementary material

Appendix S1: Management action detail

1.1 Vehicle collision hotspot management

Wildlife roadkill remains problematic because the primary cause, vehicular traffic, cannot be banned, only managed or fenced off, and it is apparent that ecologists and engineers alone have not been able to resolve the issues (Taylor and Goldingay, 2010). There remains the need for the managers of both highways (State and federal governments) and local roads (local councils) to undertake actions in at least some of the hotspots (zones with frequent road-kill), also called blackspots. Education, management, and compliance measures have not yet been able to limit the threat of vehicles, although such actions are consistent with road safety measures in general. There is a need for ongoing refinement of methodology to accurately delineate and prioritise, and then monitor road hotspot areas for koalas and other fauna for trends over time. Specific measures to minimise risks to crossing fauna need to be carefully selected to suit the road design, placement, traffic volumes and speeds. Avoiding road construction in areas occupied by koalas is an obvious solution, but where this is not feasible or in the case of existing infrastructure, it is often possible to provide safe fauna crossing structures subject to adequate justification and the necessary political will and funding.

1.2 Wild and domestic dog management

Both domestic dogs and wild dogs/dingoes are an important threat to native animals (Doherty et al., 2017). The distribution of wild dogs/dingoes in New South Wales (NSW) is largely confined to the east coast and ranges, with more certainty of records in the north-eastern part of NSW (Lunney et al., 2021). Domestic dogs are also present throughout much of the area. The number of registered dogs as of September 2020 are 15,196 (Ballina), 11,990 (Byron), 17,284 (Lismore) and 31,770 (Tweed) (NSW Office of Local Government, 2021). Assessments of the impact of domestic dogs on native animals are rare. However, in a detailed study of fire and dogs in Port Stephens in coastal NSW just north of Newcastle, dog attacks were found to be the cause of 43% of koala deaths, identifying dog attacks as a major management issue (Lunney et al., 2007, Lunney et al., 2004). The dogs were most likely domestic dogs, or domestic dogs that had become feral, but unlikely to be recognised as dingoes because of the long history of European settlement in Port Stephens from 1801

(Knott et al., 1998). Wild dogs were identified as a major cause of death (at least 49.5%) in the koala population in eastern Moreton Bay (Beyer et al., 2018).

The complexity of managing dogs and koalas becomes more apparent the more we find from research into koala predators and koala movements. The threat may be intensified at night, when koalas are moving, or in the aftermath of habitat alteration or degradation, such as in a post-fire forest, or clearing for roads, crops or housing development. Wild dogs/ dingoes are considered a strongly interactive species and are likely to have significant functional importance as apex carnivores in the Australian landscape, contributing towards biodiversity conservation by suppressing other introduced predators such as cats and foxes (Dickman et al., 2014, Smith, 2015). Hence, decisions about when it may be necessary to undertake wild dog control in support of koala conservation should be based on sound evidence from monitoring programs and control measures should be targeted at the local scale.

1.3 Disease and injury management

In NSW, disease and injury management is almost entirely carried out by volunteers (DPIE, 2020). Haering et al. (2020) surveyed the views of veterinary professionals in NSW about the services they provide to the volunteer wildlife rehabilitation sector. They found in NSW that this group provides an essential network of support for the rehabilitation of sick and injured free-living native animals. Nearly all of the surveyed private veterinary practices provided some type of service pro-bono. However, it was the koala rescue and rehabilitation groups in NSW who carried most responsibility for month after month during the massive 2019-2020 bushfires. Since the massive public response to the impact of these bushfires, a number of wildlife hospitals have been established in the northern rivers area that are operated by these groups and where the vast majority of disease and injury management actions are now undertaken.

1.4 Habitat loss and restoration

Besides addressing the factors that directly result in koala mortality, the difficult and often political matter of avoiding habitat loss where economic development is pitted against habitat conservation, as well as the difficult task of restoring habitat, are also crucial. Habitat loss can be divided into avoidable and unavoidable scenarios. Avoidable habitat loss consists of those instances where a reasonable alternative exists. Unavoidable habitat loss are those instances

where development was already approved, or very likely to be approved, such as for major infrastructure projects. The potential for destruction of habitat due to natural disasters and climate change were also included in estimations for unavoidable habitat loss. In historical perspective, habitat loss is the primary cause of the reduced populations of koalas in NSW (Knott et al., 1998, Lunney et al., 2016, McAlpine et al., 2015), now compounded by climate change, with roadkill, dogs, and disease becoming increasingly important (McAlpine et al., 2015).

Habitat protection differs from habitat restoration. The former is a policy and planning mechanism, enforceable by planning law with the objective of preventing habitat from being cleared for commercial purposes, including housing estates, golf courses, and other non-farm activities. In contrast, habitat restoration involves planting koala food trees and associated species in areas previously cleared or disturbed by human activity, or improving the condition of existing degraded habitat. Local councils, conservation and koala interest groups have taken on the task of habitat restoration through the delivery of local and regional projects such as Tweed Byron Koala Connections (https://www.tweed.nsw.gov.au/environment/native-plants-wildlife/native-animals/koalas, last accessed 17 September 2021).

1.5 Research

The impact of research on koala population size was excluded from the study. Throughout the course of the discussion phase, it became clear that research influenced each component of the model very differently and would require further investigation to untangle these effects. A response applied broadly to the final results would not provide further clues towards prioritising management actions, but would instead increase uncertainty around each management action. Experts recruited for this study posited that research applied to one action (e.g., wild dog management) would have different outcomes for koalas than research applied to any other action (e.g., disease management and prevention). In addition, participants highlighted numerous assumptions that would need to be considered with regards to ‘research’ in the context of each management action. Thus, only a very broad set of values would be sufficient to encompass all the necessary assumptions associated with this question.

References

Beyer, H. L., de Villiers, D., Loader, J., Robbins, A., Stigner, M., Forbes, N. and Hanger, J. (2018) 'Management of multiple threats achieves meaningful koala conservation outcomes', Journal of Applied Ecology, 55(4), pp. 1966-1975.

Dickman, C. R., Glen, A. S., Jones, M. E., Soule, M. E., Ritchie, E. G. and Wallach, A. D. (2014) 'Strongly interactive carnivore species: maintaining and restoring ecosystem function', in Glen, A.S. & C.R., D. (eds.) Carnivores of Australia, Past, Present, and Future. Collingwood, Victoria. : CSIRO Publishing, pp. 301-322.

Doherty, T. S., Dickman, C. R., Glen, A. S., Newsome, T. M., Nimmo, D. G., Ritchie, E. G., Vanak, A. T. and Wirsing, A. J. (2017) 'The global impacts of domestic dogs on threatened vertebrates', Biological Conservation, 210, pp. 56-59.

DPIE (2020) NSW Volunteer Wildlife Rehabilitation Sector Strategy 2020-2023, Parramatta, NSW.

Haering, R., Wilson, V., Zhuo, A. and Stathis, P. (2020) 'A survey of veterinary professionals about their interactions with free-living native animals and the volunteer wildlife rehabilitation sector in New South Wales, Australia', Australian Zoologist, 41(2), pp. 254-282.

Knott, T., Lunney, D., Coburn, D. and Callaghan, J. (1998) 'An ecological history of Koala habitat in Port Stephens Shire and the Lower Hunter on the Central Coast of New South Wales, 1801-1998', Pacific Conservation Biology, 4(4), pp. 354-368.

Lunney, D., Gresser, S., E. O'neill, L., Matthews, A. and Rhodes, J. (2007) 'The impact of fire and dogs on Koalas at Port Stephens, New South Wales, using population viability analysis', Pacific Conservation Biology, 13(3), pp. 189-201.

Lunney, D., Gresser, S. M., Mahon, P. S. and Matthews, A. (2004) 'Post-fire survival and reproduction of rehabilitated and unburnt koalas', Biological Conservation, 120(4), pp. 567-575.

Lunney, D., Sonawane, I., Shannon, I., Hope, B. and Crowther, M. S. (2021) 'Combining cameras and citizen science to define the distribution and behaviour of dingoes and foxes in New South Wales', Australian Zoologist, 41(3), pp. 608-642.

Lunney, D., Wells, A. and Miller, I. (2016) 'An ecological history of the koala Phascolarctos cinereus in coffs harbour and its environs, on the mid-north coast of New South Wales, c1861-2000', Proceedings of the Linnean Society of New South Wales, 138, pp. 1-48.

McAlpine, C., Lunney, D., Melzer, A., Menkhorst, P., Phillips, S., Phalen, D., Ellis, W., Foley, W., Baxter, G., de Villiers, D., Kavanagh, R., Adams-Hosking, C., Todd, C., Whisson, D., Molsher, R., Walter, M., Lawler, I. and Close, R. (2015) 'Conserving koalas: A review of the contrasting regional trends, outlooks and policy challenges', Biological Conservation, 192, pp. 226-236.

Appendix S2: Individual expert sub-model template with equations

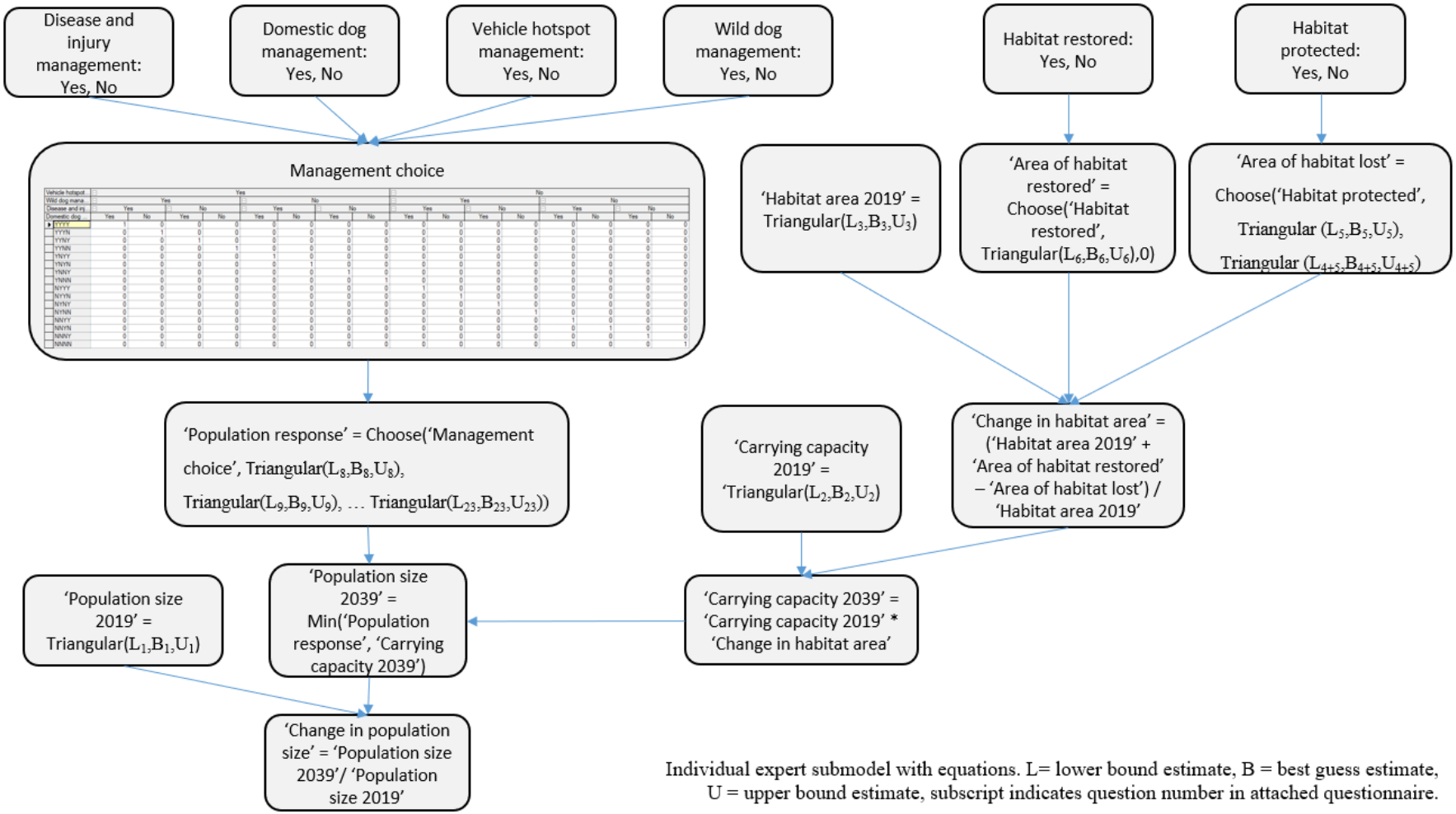

Figure S1: Design of individual expert sub-model template with equations

Appendix S3: Expert elicitation questionnaire template

Questionnaires were modified for second-round estimates to display to experts their previous estimate and allow room for recording a new value.

Assessment details

Name of Taxon: *Phascolarctos cinereus*

Region of interest: **Coastal region**

Date (dd/mm/yy):	
Name of Assessor:	
Time start (24 hour clock):	

Events	Lower bound: Realistically, what do you think is the lowest plausible value for (event x)?	Upper bound: Realistically, what do you think is the highest plausible value for (event x)?	Best estimate: Realistically, what is your best guess for the value for (event x)?	Confidence: How confident are you that your interval, from lowest to highest, could capture the true value of (event x)? Please enter a number between 50% and 100%.	Comments
1. **Mature population size:** As at July 2019, what is the number of koalas (mature individuals) in the region?	Lower bound	Upper bound	Best estimate	Confidence	Comments
2. Current carrying capacity: As at July 2019, what is the current ecological carrying capacity of the region? (number of koalas that the region could support)	Lower bound	Upper bound	Best estimate	Confidence	
3. Current coverage: As at July 2019, how much area in the region is considered koala habitat? Please answer in hectares.	Lower bound	Upper bound	Best estimate	Confidence	
4. Avoidable habitat loss: How much avoidable habitat loss will occur in the region in the next 20 years? (hectares)	Lower bound	Upper bound	Best estimate	Confidence	
5. **Unavoidable habitat loss:** How much unavoidable habitat loss will occur in the region in the next 20 years? (hectares)	Lower bound	Upper bound	Best estimate	Confidence	
6. **Habitat restoration:** What is the maximum amount of area that could be restored in the next 20 years? (hectares)	Lower bound	Upper bound	Best estimate	Confidence	
7. **Research:** How much would you expect targeted research to increase the efficiency of each management action?	Lower bound	Upper bound	Best estimate	Confidence	

The following questions consider management actions implemented in the **coastal region.**

	Management actions implemented (Yes/No)				**Lower bound:** Assume habitat is not a limiting factor. Realistically, what is the lowest plausible number of koalas you would expect in the region after 20 years given the following combinations of management actions?	**Upper bound:** Assume habitat is not a limiting factor. Realistically, what is the highest plausible number of koalas you would expect in the region after 20 years given the following combinations of management actions?	**Best estimate:** Assume habitat is not a limiting factor. Realistically, what is your best estimate for the number of koalas you would expect in the region after 20 years given the following combinations of management actions?	confident are you that your interval, from lowest to highest, could capture the true value of the number of koalas in the region after 20 years? Please enter a value between 50% and 100%.
	Vehicle hotspots managed	Wild dogs baited	Disease and injury management improved	Domestic dogs managed				
8	Yes	Yes	Yes	Yes				
9	Yes	Yes	Yes	No				
10	Yes	Yes	No	Yes				
11	Yes	Yes	No	No				
12	Yes	No	Yes	Yes				
13	Yes	No	Yes	No				
14	Yes	No	No	Yes				
15	Yes	No	No	No				
16	No	Yes	Yes	Yes				
17	No	Yes	Yes	No				
18	No	Yes	No	Yes				
19	No	Yes	No	No				
20	No	No	Yes	Yes				
21	No	No	Yes	No				
22	No	No	No	Yes				
23	No	No	No	No				

Appendix S4: Estimated change in population size (Table 3)

Table S1: Extension table of Table 3, showing mean and standard deviation.

Scenario	Code	Action						Change in population size by 2039													
		Habitat protected	Habitat restored	Disease and injury management	Domestic dog management	Vehicle strike hotspot management	Wild dog management	Coastal landscape					Hinterland landscape					Riverine landscape				
								mean	**median**	**min**	**max**	**SD**	**mean**	**median**	**min**	**max**	**SD**	**mean**	**median**	**min**	**max**	**SD**
No change to management *	s1							**0.79**	0.76	0.37	2.18	0.19	**0.91**	0.87	0.44	2.44	0.22	**0.73**	0.69	0.34	2.16	0.18
Single management action	s2	x						**0.84**	0.80	0.39	2.27	0.20	**0.92**	0.88	0.41	2.50	0.23	**0.77**	0.73	0.38	2.01	0.18
	s3		x					**0.81**	0.78	0.36	2.23	0.20	**0.91**	0.87	0.42	2.28	0.22	**0.77**	0.73	0.33	2.04	0.18
	s4			x				**0.96**	0.92	0.48	2.35	0.21	**1.04**	0.99	0.50	2.48	0.24	**1.02**	0.99	0.48	2.35	0.21
	s5				x			**0.88**	0.84	0.37	2.30	0.21	**1.05**	1.00	0.51	2.79	0.25	**0.93**	0.90	0.45	2.23	0.20
	s6					x		**0.90**	0.86	0.38	2.30	0.22	**1.08**	1.04	0.55	2.93	0.25	**0.95**	0.92	0.45	2.33	0.21
	s7						x	**0.85**	0.81	0.38	2.13	0.20	**1.06**	1.02	0.52	2.59	0.25	**0.90**	0.86	0.44	2.26	0.20
All management actions	s33	x	x	x	x	x	x	**1.26**	1.22	0.61	2.90	0.26	**1.29**	1.24	0.62	2.83	0.27	**1.43**	1.40	0.78	3.02	0.26

Appendix S5: Estimated change in population size (Table 4)

Table S2: Extension of Table 4, showing mean and standard deviation.

Scenario	Scenario code	Action						Change in population size by 2039													
		Habitat protected	Habitat restored	Disease and injury management	Domestic dog management	Vehicle strike hotspot management	Wild dog management	Coastal landscape					Hinterland landscape					Riverine landscape				
								Mean	**Median**	**Min**	**Max**	**SD**	**Mean**	**Median**	**Min**	**Max**	**SD**	**Mean**	**Median**	Min	Max	SD
Habitat protection + 1 other	s8	x	x					**0.85**	0.82	0.39	2.25	0.20	**0.93**	0.88	0.43	2.34	0.22	**0.79**	0.75	0.37	2.06	0.19
	s9	x		x				**1.03**	0.99	0.50	2.40	0.22	**1.08**	1.04	0.52	2.48	0.25	**1.11**	1.08	0.58	2.49	0.21
	s10	x			x			**0.95**	0.91	0.39	2.40	0.22	**1.09**	1.05	0.52	3.40	0.26	**1.02**	0.98	0.48	2.40	0.21
	s11	x				x		**0.97**	0.93	0.40	2.35	0.23	**1.12**	1.07	0.50	3.25	0.26	**1.04**	1.01	0.51	2.61	0.21
	s12	x					x	**0.91**	0.87	0.41	2.33	0.22	**1.11**	1.07	0.55	2.65	0.26	**0.98**	0.95	0.49	2.20	0.21
Habitat restoration + 1 other	s13		x	x				**1.00**	0.97	0.45	2.38	0.22	**1.06**	1.01	0.52	2.53	0.25	**1.17**	1.14	0.58	2.44	0.23
	s14		x		x			**0.93**	0.90	0.40	2.25	0.22	**1.07**	1.02	0.49	2.51	0.25	**1.06**	1.03	0.51	2.38	0.23
	s15		x			x		**0.94**	0.90	0.41	2.59	0.22	**1.10**	1.05	0.53	2.95	0.25	**1.08**	1.05	0.51	2.39	0.23
	s16		x				x	**0.89**	0.85	0.40	2.40	0.21	**1.08**	1.04	0.52	2.68	0.25	**1.02**	0.99	0.50	2.75	0.23
Domestic and wild dog control + 1 other	s17				x		x	**0.91**	0.87	0.38	2.36	0.22	**1.08**	1.04	0.52	2.91	0.26	**1.00**	0.96	0.49	2.26	0.21
	s18	x			x		x	**0.98**	0.94	0.44	2.50	0.23	**1.13**	1.09	0.52	2.57	0.26	**1.09**	1.06	0.57	2.52	0.22
	s19		x		x		x	**0.95**	0.91	0.43	2.58	0.22	**1.10**	1.06	0.49	2.78	0.26	**1.12**	1.09	0.55	2.42	0.22
	s20			x	x		x	**1.02**	0.99	0.47	2.41	0.22	**1.18**	1.13	0.57	2.84	0.26	**1.03**	1.00	0.48	2.39	0.21
	s21				x	x	x	**0.95**	0.91	0.43	2.47	0.22	**1.11**	1.07	0.54	2.60	0.26	**1.02**	0.99	0.49	2.57	0.22
Disease, injury, and vehicle	s22			x		x		**1.02**	0.99	0.48	2.53	0.22	**1.15**	1.11	0.58	2.81	0.26	**1.07**	1.03	0.53	2.53	0.22
	s23	x		x		x		**1.12**	1.08	0.53	2.89	0.24	**1.21**	1.17	0.59	2.88	0.27	**1.17**	1.14	0.59	2.53	0.22
	s24		x	x		x		**1.10**	1.06	0.49	2.68	0.24	**1.18**	1.13	0.57	2.68	0.26	**1.24**	1.21	0.54	2.73	0.24

hotspot + 1 other	s25			x	x	x		**1.05**	1.02	0.53	2.59	0.22	**1.18**	1.13	0.53	2.67	0.26	**1.06**	1.03	0.55	2.24	0.22
	s26			x		x	x	**1.02**	0.98	0.49	2.58	0.22	**1.19**	1.14	0.59	2.64	0.26	**1.09**	1.06	0.55	2.45	0.22
Missing one action	s27		x	x	x	x	x	**1.16**	1.12	0.57	2.66	0.24	**1.23**	1.18	0.63	2.70	0.26	**1.33**	1.29	0.62	2.85	0.25
	s28	x		x	x	x	x	**1.18**	1.14	0.56	2.68	0.24	**1.27**	1.22	0.65	2.88	0.27	**1.25**	1.21	0.68	2.80	0.23
	s29	x	x		x	x	x	**1.10**	1.06	0.53	2.72	0.25	**1.18**	1.14	0.56	2.65	0.27	**1.26**	1.23	0.53	2.76	0.25
	s30	x	x	x		x	x	**1.19**	1.15	0.54	2.57	0.25	**1.27**	1.22	0.65	2.76	0.27	**1.37**	1.34	0.71	2.84	0.25
	s31	x	x	x	x		x	**1.18**	1.14	0.51	2.71	0.25	**1.25**	1.21	0.60	2.67	0.28	**1.28**	1.25	0.69	2.66	0.25
	s32	x	x	x	x	x		**1.22**	1.18	0.61	2.72	0.26	**1.26**	1.21	0.63	2.72	0.28	**1.32**	1.28	0.70	2.64	0.25

Appendix S6: Mean and range of individual best guess estimates

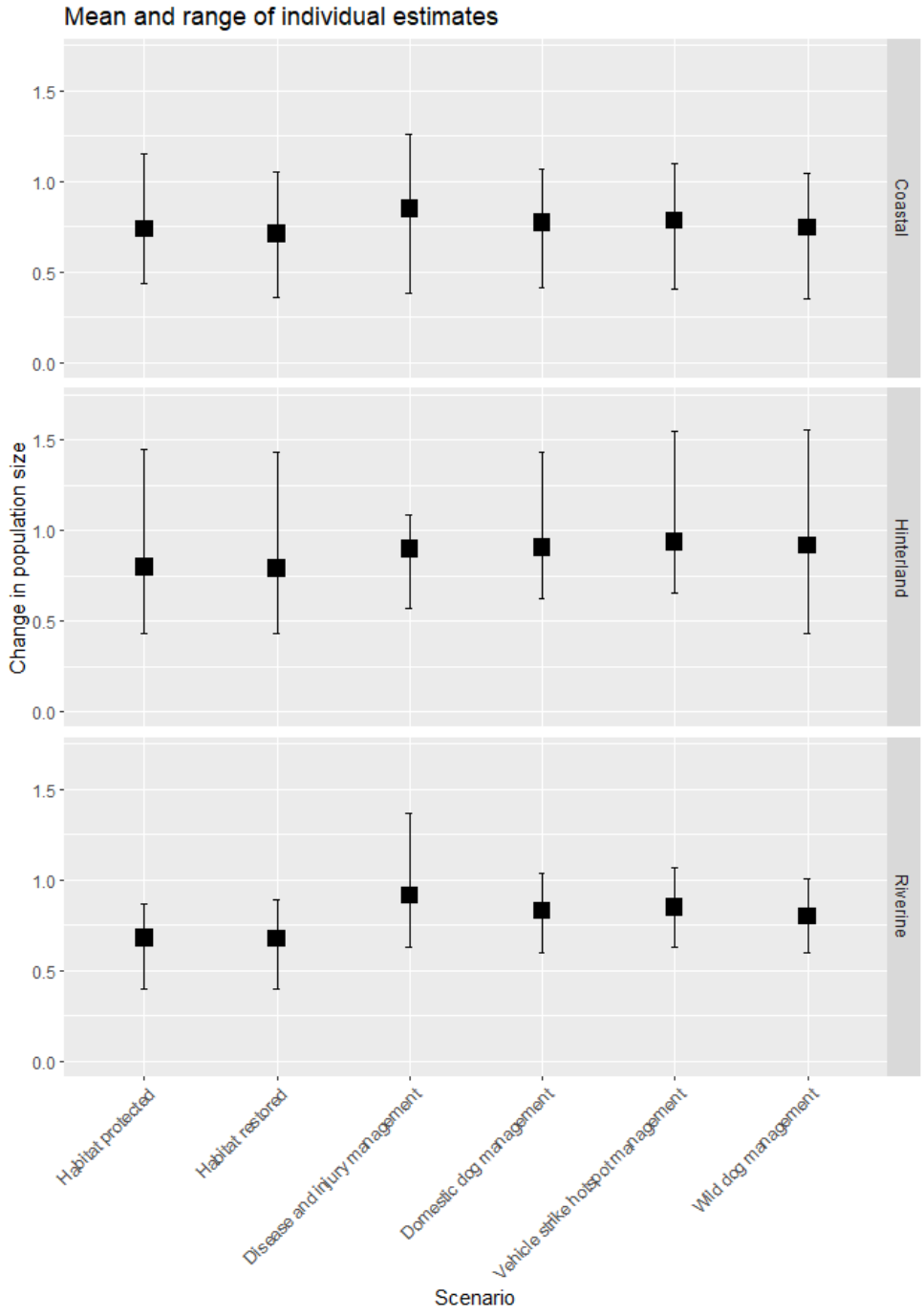

Figure S2: Mean and range of individual best guess estimates for change in koala population size between 2019 and 2039, in response to 6 management scenarios, across three regional landscapes. Here, the median (best guess) output is taken from each individual sub-model in the Bayesian Network (Figure 3, Appendix S2). The minimum, mean, and maximum values of the individual best guesses are shown

Appendix S7: Estimated changes in population size - distribution

Table S3: Scenario definitions used in Table 4.

Scenario	Scenario code	Action					
		Habitat protected	Habitat restored	Disease and injury management	Domestic dog management	Vehicle strike hotspot management	Wild dog management
No actions	s1						
One action	s2	x					
	s3		x				
	s4			x			
	s5				x		
	s6					x	
	s7						x
Habitat protection + 1 other	s8	x	x				
	s9	x		x			
	s10	x			x		
	s11	x				x	
	s12	x					x
Habitat restoration + 1 other	s13		x	x			
	s14		x		x		
	s15		x			x	
	s16		x				x
Domestic and wild dog control + 1 other	s17				x		x
	s18	x			x		x
	s19		x		x		x
	s20			x	x		x
	s21				x	x	x
Disease, injury, and vehicle hotspot + 1 other	s22			x		x	
	s23	x		x		x	
	s24		x	x		x	
	s25			x	x	x	
	s26			x		x	x
Missing one action	s27		x	x	x	x	x
	s28	x		x	x	x	x
	s29	x	x		x	x	x
	s30	x	x	x		x	x
	s31	x	x	x	x		x
	s32	x	x	x	x	x	
All actions	s33	x	x	x	x	x	x

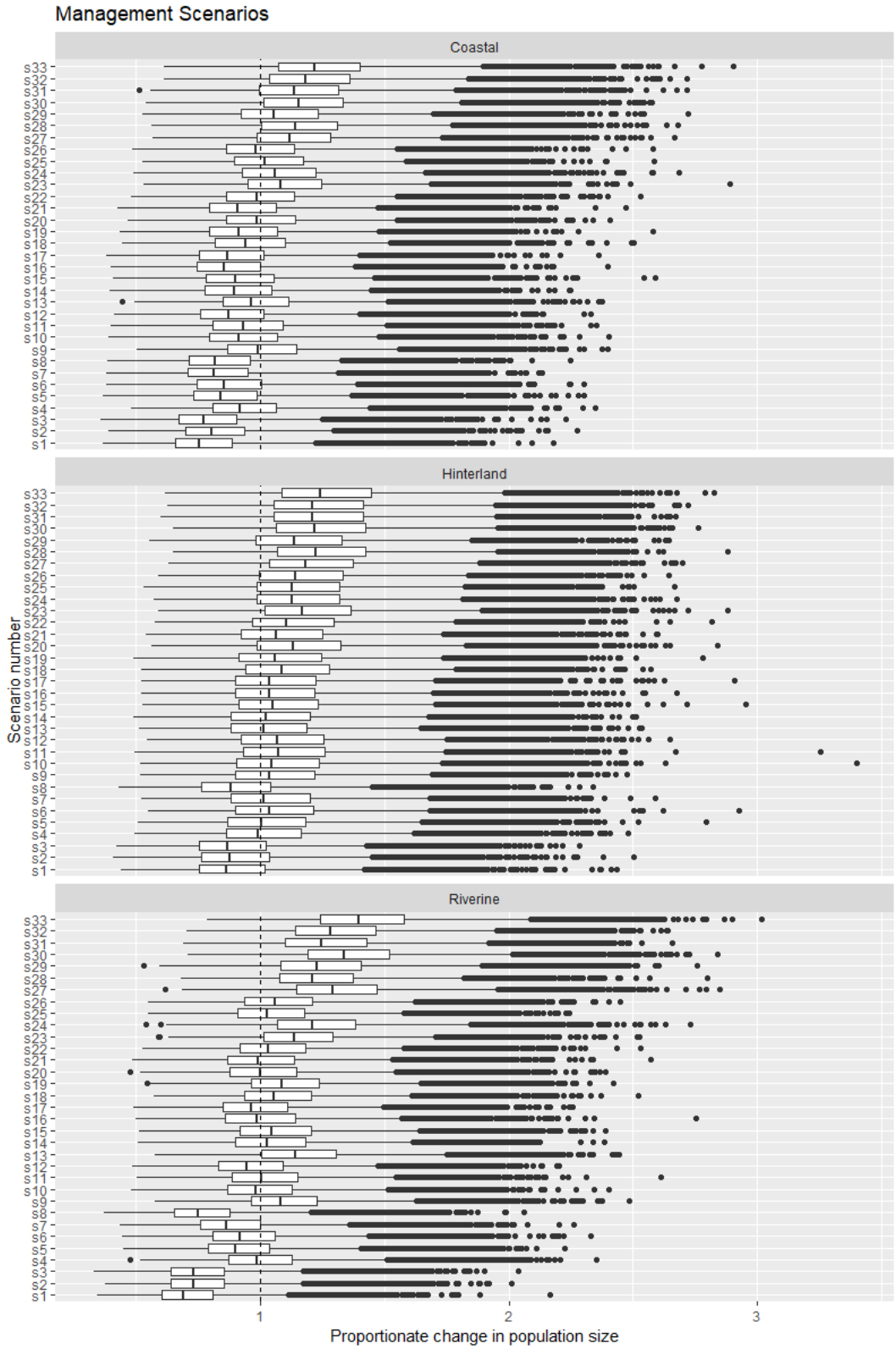

Figure S3: Estimated changes in koala population size over 20 years (2019-2039), summarised by first quartile, median and third quartile. Whiskers extend to a maximum of 1.5 * IQR (inter-quartile range), and any values outside of this range are plotted individually as outliers. The value 1 is marked to indicate the point at which there is no change in population size. Values larger than this indicate an increase in population size, and smaller values indicate a decrease in population size. Scenario definitions are provided in Table S3.