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The Factors Affecting the Use of Fauna Underpasses by Quenda and Bobtail Lizards

Report to Main Roads Western Australia

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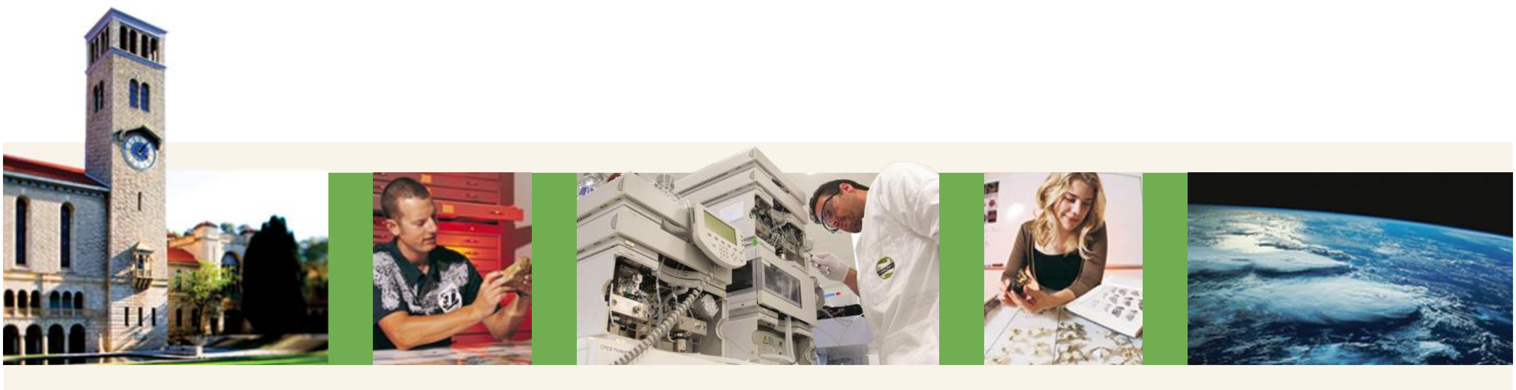

Executive Summary

The construction of fauna underpasses is becoming increasingly common in road construction projects in Australia. However, there is a paucity of data relating to the factors associated with their use by native fauna. We monitored 10 fauna underpasses for a period of 13 months in the southern metropolitan area of Perth, Western Australia to determine the factors associated with use by southern brown bandicoots or quenda (*Isoodon obesulus fusciventer*) and western bobtail lizards (*Tiliqua rugosa rugosa*), the two native species that mostly used these underpasses. We also trapped in the area directly around each underpass five times in order to determine the size of the populations of these two species around the structures and derive the mean frequency of use and the proportion of the known population that used each crossing structure. All quenda and bobtail lizards were marked with passive implant transponders (PIT tags) and PIT tag readers and motion-activated cameras recorded the total use and the number of individual quenda and bobtails lizards that used each underpass. Mean weekly frequency of use corrected for population size and the proportion of the marked population that used each underpass were modelled using generalized linear models against factors hypothesised to impact underpass use. These were underpass length, cross sectional area, vegetation cover at the entrances, the presence or absence of logs and branches in the underpass (furniture), use by feral predators and time since construction.

Underpass length was found to be negatively related to the frequency of use by quenda and vegetation cover was found to be positively correlated. Time since construction was found to be negatively correlated with the proportion of the population of quenda that used the underpasses. For western bobtail lizards none of the factors tested were found to be related to the frequency of use, but time since construction and vegetation cover were both found to be negatively related to the proportion of the population that used the underpass. Based on these results we recommend that the length of underpasses should be kept to a minimum possibly through the use of vegetated median strips with two short underpasses connecting to habitat on either side of the road. This would be highly likely to result in a greater amount of underpass use than one long underpass connecting the two sides of the road. The cause of the reduction in the proportion of both species using the underpasses over time needs further investigation as it may indicate long term negative consequences of underpass use.

Contents

Introduction

Fauna underpasses are now commonly built under newly constructed roads in Australia in an attempt to reduce the impact of fragmentation on wildlife populations. Several studies have demonstrated that both native and introduced fauna will use them to cross roads (Bond and Jones, 2008, Goosem *et al.*, 2005, Taylor and Goldingay, 2003, Harris *et al.*, 2010), but despite the large amounts of money spent building these structures there are little data available on the characteristics of these structures that encourage or discourage their use by native Australian fauna. This is largely due to a lack of replication in many published studies of underpass use, which has severely reduced the ability of authors to draw strong conclusions from their results (Roedenbeck *et al.*, 2007, Grift *et al.*, 2013, van der Ree *et al.*, 2008). All studies on underpass use published in Australia with the exception of Harris et al. (Harris *et al.*, 2010) have used either sand pads or motion activated cameras to determine which animals were using them (Bond and Jones, 2008, Ecologia-Environmental-Consultants, 1995, Taylor and Goldingay, 2003, Mansergh and Scotts, 1989, Hayes and Goldingay, 2009, Goosem *et al.*, 2005). The major drawback of this approach is that these methods do not provide information on the number of individual animals that are utilising the structures. Without data on the number of individual animals using these structures it is very difficult to assess whether they are likely to be of value at a population level. Also lacking in the majority of the currently published studies on underpass use is an assessment of the population sizes of the species of interest in the area surrounding the underpasses. Of the papers published from Australia on fauna underpasses only one study has accounted for the population sizes of the study species (Mansergh and Scotts, 1989). This is surprising, because this information is critical in determining the value of these structures as a limited amount of use of an underpass may be simply a reflection of a small or low density population in the area surrounding the underpasses rather than being a result of underpass design or management.

This study aimed to determine which factors are related to the use of underpasses by the quenda, or southern brown bandicoot (*Isoodon obesulus fusciventer)* and the western bobtail lizard (*Tiliqua rugosa rugosa)* and to overcome some of the shortfalls previously mentioned. The quenda is one of a small number of native terrestrial mammals that continue to persist in urban areas of the southwest of WA. Many of the fauna underpasses that have been built in the Perth metropolitan area have been aimed at facilitating the movement of quenda between areas of fragmented habitat. To date there have been only two studies of the use of fauna underpasses by quenda in the south west of WA. A study of seven fauna underpasses built under the Kwinana Freeway at Mandogalup in 1994 found that quenda used the structures with two passages recorded over a 20 day period (10 days in December, 10 days in May, Ecologia-Environmental-Consultants, 1995), whilst a more recent study of three fauna underpasses built under Roe Highway in Leeming found that quenda began to use the underpasses almost immediately and in one case were found to use the underpasses while it was still being constructed. Ecologia Environmental Consultants (1995) reported that there were no relationships between the frequency of underpass use by quenda and underpass characteristics such as length, distance to vegetation, vegetation cover and leave litter. However, the short duration of their monitoring would have reduced their ability to determine significant relationships. Harris et al. (2010) found that at least 8 different individual quenda used one of the three underpasses studied, but that foxes were potentially targeting quenda using the underpasses, which may have been a cause of the local extinction of one of the populations of quenda in the study.

Southern brown bandicoots prefer areas of dense low vegetation (Haby *et al.*, 2013), presumably because this provides them with protection from foxes and cats, which are their two main predators (Coates and Wright 2003). Therefore we expected to find a positive relationship between the percentage of vegetation cover near the entrances to an underpass and the frequency of use by quenda. For the same reason we also expected that having cover within the underpass in the form of logs and branches (commonly referred to as furniture) would be positively related to the amount of use by quenda.

The opening size and the length of underpasses has been found to have a significant influence on the frequency of use by small mammals, who tend to show a preference for structures with smaller cross sectional areas (Mata *et al.*, 2008, Rodriguez *et al.*, 1996). Rodriquez *et al.* (1996) suggested that this preference may have been related to reduced predation risk from aerial predators. The main predators of quenda are the European red fox and the cat and therefore the size of fauna underpasses is not likely to impact on predation risk as strongly. However, underpasses with greater cross sectional area and shorter length are likely to be relatively better lit than smaller underpasses which may help small prey species such as quenda to assess predation risk. Quenda have been shown not to respond to the scent of introduced predators and therefore must rely on visual or auditory cues (Mella *et al.*, 2011). Underpasses with a larger cross sectional area and shorter length were therefore expected to be preferred by quenda as they would be more able to assess the presence of predators in these structures.

The bobtail lizard is a medium sized squamate reptile that has also persisted in urban areas across Australia. This species is particularly understudied in urban environments. However, they are known to have a lifespan exceeding 20 years (Bull, 1995), show strong site fidelity (Bull and Freake, 1999) and are found in areas of dense and sparse vegetation, including urban areas. They take refuge under dome shaped bushes where available (Kerr *et al.*, 2003, Kerimofski, 2013), but they are also commonly found utilising other forms of cover such as sheets of metal where cover from vegetation is not present (Bush *et al.*, 2007). We therefore expected use of underpasses by bobtail lizards to be positively related to the percentage of vegetation cover at the underpass entrances. Bobtail lizards have relatively small home ranges of 2.38±0.35 ha in the banksia woodlands of the swan coastal plain (Kerimofski, 2013) and we therefore expected to find a negative relationship between the length of the underpass and the likelihood of use by this species.

Methods

Study sites

10 fauna underpasses at five different sites across the southern metropolitan area of Perth, Western Australia were selected for use in the study (Figure 1). Site selection was based primarily on the presence of appropriate habitat in the vicinity of the fauna underpasses and signs such as diggings, which suggested the presence of quenda in those areas. At each underpass a 'catchment area' was defined that extended 200m in either direction parallel to the road and 200m into the surrounding vegetation perpendicular to the road.

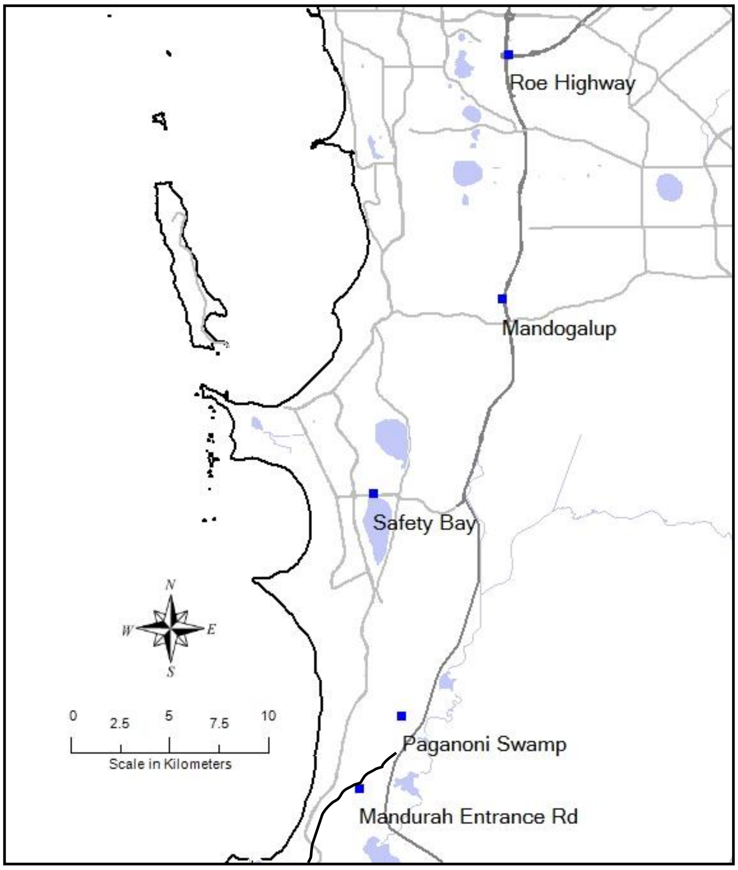

Figure 1. Location of the five study sites where ten fauna underpasses were studied for the use by native and introduced fauna.

The fauna underpasses varied in length, cross sectional area, density of vegetation at the entrances and in the presence or absence of furniture (primarily logs and branches) within the underpass. The roads at all sites were fenced including a buried skirting to stop fauna from digging under the fence. The height of the fencing varied from 600mm to 1800mm with a buried skirt of at least 300mm. Vegetation cover was assessed for each entrance to the underpass using the quadrant cover method (QCM) which measures the degree to which the microhabitat provides concealment from visually searching predators (Glen *et al.*, 2010). Using this method vegetation cover was assessed 1.0 m from the entrance to the underpass, 5.0m from the entrance directly in front of the underpass and at 45° to either side. The means of all eight measurements (four from each entrance) were used as the measure of vegetation cover for each underpass. The attributes of each underpass and its surroundings are shown in Table 1.

Table 1. Attributes of the ten fauna underpasses studied for their use by fauna. Dimensions are given as diameter for round culverts or width and height of square culverts.

Site	Underpass	Dimensions (m)	Cross Sectional Area (m^2)	Length (m)	Furniture present	Mean vegetation cover (%)	Time since construction (years)
Paganoni	1	0.6x0.6	0.36	68	No	0	3
Swamp	2	0.9 diam.	1.13	66	No	0	3
	3	0.6x0.6	0.36	64	No	0	3
Safety Bay	4	1.2x1.2	1.44	36	Yes	22	12
	5	1.2x1.2	1.44	41	Yes	44	12
Mandogalup	6	0.6 diam.	0.28	88	No	46	19
Roe Highway	7	1.2x1.2	1.44	34	No	38	7
	8	1.2x0.45	0.54	23	Yes	50	7
Mandurah	9	0.9 diam.	1.13	54	Yes	0	2
Entrance Rd	10	0.9 diam.	1.13	41	No	4	2

Fauna trapping

At the entrance to each underpass traps were set out in a grid with 50 m spacing between traps. Each grid extended 200m in either direction from the underpass entrance parallel to the road and 200m into the surrounding vegetation perpendicular to the road. This gave a maximum of 45 trap sites at each underpass entrance over an area of up to 8ha. At some underpasses the area trapped was less than 8 ha due to the presence of fences that bordered the reserve, or the presence of permanent water bodies (river or lake). Medium sized mammals and reptiles were trapped using medium sized wire cage traps (220x220x450mm, Sheffield Wire Works, Welshpool) baited with universal bait (rolled oats, peanut butter and sardines) in spring 2011, autumn, winter and spring 2012 and winter 2013 with the exception of the Roe Highway site, which was not trapped in spring of 2011 due to difficulties obtaining permission from land holders.

All small and medium sized native mammals (quenda, brushtail possums, brush-tailed phascogales and chuditch) and medium sized reptiles (bobtail lizards, western bluetongues and varanid spp.) captured were identified using a passive implant transponder or PIT tag (Trovan Unique).

Underpass monitoring

All of the underpasses used in the study were fitted with a motion activated infrared camera (Reconyx HC600) and a PIT tag reader consisting of a flat-bed antenna and a PIT tag decoder. The 1200mm wide underpasses had 2 flatbed antennae installed side by side to ensure that any PIT tagged animals were recorded. The PIT tag readers were run from deep cycle batteries recharged by solar panels to ensure that they were functioning continuously. The photographs captured by the infrared cameras were used to record data on the number of uses of the underpasses by all species and the data recorded by the PIT tag readers were used to identify the number of individuals of each species that used the underpasses. House mice (*Mus musculus*) were found to be living in a number of the underpasses and they were therefore excluded from the data collected as it was not possible to determine which animals were using the underpass to move across the road and which were living within the structure.

Data analyses

Population sizes of quenda were estimated for each of the sites at each of the trapping occasions using a robust design mark-recapture analysis in Program Mark. Several different models were tested in Program Mark with capture probability varying between trapping sessions, within trapping sessions over time or as a result of a behavioural response. These models were ranked using Akaike's Information Criterion correct for small sample sizes (AICc) and the model with the lowest AICc value was chosen as the best fit for the data (Burnham and Anderson, 2002). Based on the population estimates determined by mark-recapture weekly population estimates for the catchment area of each underpass were calculated assuming that the population size changed linearly between trapping sessions. A frequency of use was then determined for each underpass each week as the total number of crossings divided by the population size in the catchment area. A mean weekly frequency of use was then determined for each underpass.

Population sizes could not be determined for bobtail lizards as they were found to have a very strong behavioural response to being trapped with very few animals being recaptured within each trapping session. The total number of crossing for each underpass was therefore determined for bobtail lizards without correcting for the population size within the catchment area of the underpass.

A second measure of use was also determined by calculating the proportion of the known population that used the underpass over the entire period of the study. This was calculated as the number of individual quenda or bobtail lizards known to have used the underpass divided by the total number of individuals microchipped in the catchment area of that underpass.

The factors impacting the mean frequency of use and the proportion of the known population that used the underpass were analysed using an information theoretic framework. A number of alternative *a priori* hypotheses were developed regarding the factors that may affect the use of the underpasses by these species. These hypotheses were then used to construct a number of generalized linear candidate models, each based on one of the hypotheses. Due to the limited number of underpasses (10) studied we limited the hypotheses and therefore the candidate models to those including a single explanatory variable. Interactions between the different explanatory variables were likely, however, but could not be considered in this study. Relationships between the different explanatory variables were assessed by linear correlation or logistic regression in the case of the furniture variable. The data were assessed for fit against a normal and exponential distribution using a Shapiro-Wilks W test for normality and Kolmogorov's D goodness of fit test for exponential distributions. The mean frequency of use data for quenda were not found to conform to either distribution, but when they were square root transformed they conformed to an exponential distribution ($D=0.199$, $p=0.150$). The other three data sets were found to have an exponential distribution without the need for transformation and therefore the generalized linear models were run using this distribution with a reciprocal link function. The best fitting model was chosen as the one with the lowest Akaike's Information Criterion value corrected for small sample sizes (AICc) (Burnham and Anderson, 2002). Overdispersion in the data was assessed by fitting a global model, which included all parameters from the candidate models in order to calculate c-hat (Burnham and Anderson, 2002). C-hat was not found to exceed 1.0 in any of the global models and therefore AICc was used to assess model fit. The candidate models are shown in Table 2.

Table 2. Candidate models based on hypotheses to explain variation in the use of underpasses by quenda and bobtail lizards.

Model	Parameters	Hypothesis
1	Length	There will be a negative relationship between the length of the underpass and the use by quenda and bobtail lizards
2	Cross sectional area	There will be a negative relationship between the cross sectional size of the underpass and its use by quenda and bobtail lizards.
3	Furniture	Underpasses with furniture in them will be used more by quenda and bobtail lizards than those without.
4	Vegetation cover	There will be a positive relationship between vegetation cover and use of underpasses by quenda and bobtail lizards
5	Predators	There will be a negative relationship between the amount of use of an underpass by introduced predators (foxes and cats) and its use by quenda and bobtail lizards
6	Time since construction	Use by quenda will increase with time since construction as the animals become more accustomed to the presence of the underpass.
7	-	Null model

Results

The number of times an underpass was used by quenda varied from one use by one individual to 378 uses by at least 16 individuals (Table 3). Use by bobtail lizards varied from three passages by one individual to 143 passages by eight individuals (Table 3). Other species recorded using the underpasses included the western grey kangaroo (*Macropus fuliginous*), brushtail possum (*Trichosurus vulpecula*), Gould's sand monitor (*Varanus gouldii*), western bluetongue (T*iliqua occipitalis*), dugite (*Pseudonaja affinis*) , fox (*Vulpes vulpes*), cat (*Felis catus*), rabbit (*Oryctolagus cuniculus*), black rat (*Rattus rattus*) and house mouse (*Mus musculus*). Southern heath monitors (*Varanus rosenbergi*) and black-headed monitors (*Varanus tristis*) were also recorded using the underpasses, however it was not possible to confidently determine between these two species in many photos and they were therefore reported together (Table 3). Pacific black ducks (*Anas superciliosa*) with clutches of ducklings were also recorded using two of the underpasses on two separate occasions (for example images see Appendix 1).

Western grey kangaroos used underpasses of a variety of sizes, even those as small as a 600x600mm. The use of underpass 1 was dominated by a female kangaroo and her young at foot who used the underpass several times each week.

Brushtail possums were not found to use the underpasses with any significant frequency as only one animal used underpass 2 in the 12 months of monitoring despite brushtail possums being present around six of the 10 underpasses.

Foxes were observed to use all underpasses at all sites and cats were observed using 8 of the 10 underpasses. Cats were observed using underpasses 4 and 5 very frequently and based on coat markings a total of seven different individuals were identified. One of these cats was also photographed sleeping in one of the underpasses for approximately 4-6 hours each day for a period of three weeks in August 2012.

Significant correlations were found between cross sectional area and use by predators (r^2=0.659, df=9, F=15.45, p=0.004) and between time since construction and vegetation cover (r^2=0.589, df=9, F=11.48, p=0.009).

Factors affecting underpass use by quenda

Underpass length was the factor that generated the best fitting model. However, the null model and the model with vegetation cover as the parameter also had strong support from the data (ΔAICc<2.0, Table 4). Length was found to be negatively correlated with the number of crossings and vegetation cover was found to be positively correlated with the number of crossings.

Table 4. Model selection results for the factors affecting the total number of crossings by quenda.

Model	Factor	AICc	ΔAICc	AICc Weight
1	Length	-10.00	0.00	0.644
7	- (Null)	-8.92	1.08	0.374
3	Vegetation Cover	-8.28	1.72	0.272
5	Predators	-5.92	4.08	0.084
6	Time since construction	-5.86	4.14	0.081
2	Cross Sectional Area	-5.80	4.20	0.079
4	Furniture	5.73	15.73	0.000

Table 3. Recorded use of underpasses by all species between May 2012 and May 2013. Values in parentheses denote the number of individual animals recorded. NP (not present) indicates that no individuals of the species were caught or observed in the area near the underpass.

Species		Underpass									
Common Name	**Scientific name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Quenda	*Isoodon obesulus fusciventer*	7 (2)	4 (2)	6 (2)	1 (1)	5 (2)	2 (1)	378 (16)	134 (3)	2 (1)	1 (1)
Western grey kangaroo	*Macropus fuliginosus ocydromus*	137	35	0	14	0	0	NP	NP	2	0
Brushtail possum	*Trichosurus vulpecula*	0	2	0	NP	NP	0	NP	NP	0	0
Cat	*Felis catus*	0	0	2	170	118	8	80	10	9	22
Fox	*Vulpes vulpes*	39	33	9	10	9	21	8	3	11	60
Rabbit	*Oryctolagus cuniculus*	38	1	5	18	0	0	0	0	0	1
Black rat	*Rattus rattus*	0	3	8	48	46	9	2	188	9	0
Bobtail lizard	*Tiliqua rugosa rugosa*	3 (1)	143 (8)	77 (6)	37 (3)	32 (1)	58 (3)	35 (1)	5 (1)	5 (1)	17 (1)
Southern heath monitor/Black-headed monitor	*Varanus rosenbergi/ Varanus tristis*	0	7	1	13	11	0	NP	NP	0	2
Gould's sand monitor	*Varanus gouldii*	0	0	0	NP	NP	0	NP	NP	1	0
Western bluetongue	*Tiliqua occipitalis*	0	0	0	0	2	NP	NP	NP	NP	NP
Dugite	*Pseudonaja affinis*	1	4	1	0	0	10	0	0	1	0
Pacific black duck	*Anas superciliosa*	1	1	0	0	0	0	0	0	0	0

The proportion of the microchipped quenda that used the underpasses ranged from 0.02 to 0.4 and time since construction was found to be the only parameter to strongly influence the proportion that used the underpasses (ΔAICc <2.0, Table 5). Time since construction was found to be negatively correlated with the proportion of the population that used the underpass.

Table 5. Model selection results for the factors affecting the number of individual quenda recorded using underpasses.

Model	Factor	AICc	ΔAICc	AICc weight
6	Time since construction	-9.74	0.00	0.644
7	- (Null)	-6.84	2.90	0.151
3	Vegetation Cover	-6.06	3.68	0.102
4	Furniture	-4.16	5.58	0.040
2	Cross Sectional Area	-3.73	6.01	0.032
1	Length	-3.68	6.06	0.031
5	Predators	-3.66	6.08	0.031

Factors affecting underpass use by bobtail lizards

Underpass use by bobtail lizards ranged from 3 to 143 crossings over the study period and the proportion of the microchipped individuals that used them ranged from 0.02 to 0.29. There were no clear relationships between any of the factors tested and the total number of crossings by bobtail lizards, as demonstrated by the null model having the greatest support from the data with no other models having strong support from the data (ΔAICc <2, Table 6).

Table 6. Model selection results for the factors affecting the total number of crossings of the fauna underpasses by bobtail lizards.

Model	Factor	AICc	ΔAICc	AICc weight
7	- (Null)	98.18	0.00	0.167
3	Furniture	100.20	2.02	0.061
1	Length	100.49	2.31	0.053
5	Predators	100.84	2.66	0.044
2	Cross Sectional Area	101.25	3.07	0.036
4	Vegetation Cover	101.27	3.09	0.036
6	Time since construction	101.39	3.21	0.201

Models with time since construction and vegetation cover were found to have a similar level of support to the null model in relation to the proportion of individuals that used the underpass (ΔAICc <2, Table 7). Both time since construction and vegetation cover were negatively correlated with the proportion of bobtail lizards that used the underpasses. It is important to note, however, that time since construction and vegetation cover were also positively correlated with each other.

Table 7. Model selection results for the factors affecting the proportion of individual bobtail lizards recorded using underpasses.

Model	Factor	AICc	ΔAICc	AICc weight
7	- (Null)	-14.02	0.00	0.421
6	Time since construction	-12.51	1.51	0.198
4	Vegetation Cover	-12.46	1.55	0.194
3	Furniture	-11.69	2.33	0.131
5	Predators	-11.34	2.68	0.110
1	Length	-10.97	3.05	0.092
2	Cross Sectional Area	-10.81	3.21	0.085

Discussion

Underpass length and time since construction were the two factors that had a strong negative influence on the frequency and the proportion of quenda that used the underpasses. In other words, quenda did not use long underpasses very often and use decreased over time. Vegetation cover was also found to encourage the use of underpasses by quenda, but this effect was not as strong as underpass length. These results supported our hypothesis about underpass length and vegetation cover, but the relationship between the proportion of quenda using the underpasses and time since construction was negative, which was the opposite to what we hypothesised.

None of the factors tested were found to strongly influence the frequency of use by bobtail lizards, but time since construction and vegetation cover both impacted the proportion of the bobtail lizard population that used the underpasses. The relationships between time since construction, vegetation cover and the proportion of bobtail lizards that use the underpasses were both negative, contrary to our expectations.

The presence of furniture, cross sectional area and the use of underpasses by introduced predators were all expected to influence underpass use by the two focal species, however these factors were not found to have any significant influence on either the frequency of use or the proportion of quenda or bobtail lizards that used the underpasses.

Underpass length was found to be the most important factor affecting underpass use by quenda, however the large variation in use by quenda, between 1 and 378 uses suggests that shorter underpasses are being used differently to longer ones. The shorter underpasses that were used very frequently appear to be incorporated into the home ranges of individual quenda allowing them to utilise habitat on both sides of the road, whereas the longer underpasses are being used infrequently probably during dispersal events. Whilst both of these uses of underpasses are positive for connectivity between populations they represent different processes. In situations where underpass use is very frequent and animals are using habitat on both sides of the road as part of their home range this can allow the persistence of populations in small patches that are not large enough to support viable populations on their own. However, when habitat patches are connect by long underpasses that are used infrequently this then requires the patches on either side of the road to be large enough to support self-sustaining populations. The Roe Highway site in this study is an example of the former. The habitat patches connected by underpass 7 were 5.9 and 1.0 ha in size and those connected by underpass 8 were 3.8 and 9.7 ha. The quenda populations at this site were at very high densities at the time of the study at approximately 5 animals per ha, but even at this high density the 1.0 and 3.8 ha patches would still not be capable of supporting self-sustaining quenda populations in the long term. These patches had been isolated (except for the presence of the underpasses) for 7 years at the time of the study and yet were still occupied. This demonstrates the value of the underpasses at this site which has allowed quenda to persist in these patches.

There was a negative relationship between the time since the underpasses were constructed and the proportion of both of the quenda and bobtail lizard populations that used the underpasses. This was contrary to our expectations and contrary to the results of other published studies (Clevenger and Waltho, 2003, Bond and Jones, 2008). Clevenger and Waltho (2003) found that use of underpasses by ungulates and large carnivores increased over a four- six year period after construction and Bond and Jones (2008) found that the use of fauna underpasses continued to increase in the first six months following construction. Harris *et al.* (2010) reported varying results from three underpasses with two of them showing increasing a slow increase in use by quenda over 12 months following construction and one other showing a very fast increase in the first 2 months followed by large fluctuations in use for the following 10 months. The underpasses we studied varied in age between 2 and 19 years old, but it is important to note that our study did not follow the use of these underpasses since they were first constructed. Our results do suggest that for quenda and bobtail lizards the proportion of individuals that will use these structures decreases over time, even though vegetation cover increased with time since construction. In the case of the oldest underpass in our study, this underpass was monitored shortly after it was constructed and was found to be used by quenda at that time (Ecologia-Environmental-Consultants, 1995), but this underpass was only used twice over the course of this study. Time since construction was positively correlated with vegetation cover near the underpass entrances, but vegetation cover did not influence significantly the proportion of quenda that used the underpasses. This suggests that the relationship between the proportion of the quenda population using underpasses and time since construction is a real relationship and not an artefact of the relationship with vegetation cover. The reasons for this relationship are not clear, however, it is possible that it is indicative of a negative consequence of underpass use in the long-term. Harris *et al.* (2010) suggested that predation of quenda by foxes may have been responsible for the local extinction of a quenda population where multiple individuals were recorded to frequently use a newly constructed fauna underpass. If we consider that using a fauna underpass constitutes a form of risk taking behaviour for prey species such as quenda and bobtail lizards and that risk taking behaviour is influenced by genetics, as has been shown in other species (van Oers *et al.*, 2004, Bize *et al.*, 2012), then we could reasonably expect to see a reduction in the number of individuals that are willing to use the underpass over time if underpass use results in lower survival rates. This relationship clearly warrants further study to determine if there are negative consequences for individual animals that use underpasses.

Contrary to our expectations furniture did not have any significant influence on the use of the underpasses by quenda or bobtail lizards. Particularly for quenda this result seems at odds with the finding that vegetation cover near the underpass entrance was positively correlated with the frequency of use. The provision of furniture in fauna underpasses has been suggested to encourage use by small fauna (Bond and Jones, 2008), however, there are no published data to demonstrate that Australian fauna respond positively to its presence in underpasses. There are also quite significant differences in the types of structures that are referred to as furniture in different studies. Bond and Jones (2008) found that approximately 20% of rodents and 40% of dasyurids that used fauna underpasses travelled above the floor on raised shelves or logs. However, this type of furniture was present in all of the underpasses and this did not allow for a comparison with underpasses that did not have it. Our results suggest that for quenda and bobtail lizards furniture in the form of logs and branches on the floor of the underpass did not increase their use. The underpasses used in this study had maximum dimensions of 1.2x1.2m and it is therefore possible that furniture may have a positive influence on the likelihood of small animals using underpasses larger than this, but it has no impact on the use of smaller underpasses.

Previous studies have found that underpass size has a strong influence on the frequency of use by small mammals (Rodriguez *et al.*, 1996, Mata *et al.*, 2005). In these two studies the smallest underpasses monitored were 1.2x1.2m and 1.8m in diameter respectively. All of the underpasses used in this study were equal to or smaller than this size, which may explain the lack of relationship found between cross sectional area and use by either species. These results suggest that below a certain opening size, which appears to be in the range of 1.4m^2, underpass opening size may cease to be an important determinant of use for small mammals. The largest underpasses used in this study were also used by western grey kangaroos, which are the largest native terrestrial species present in the south west of Western Australia. Therefore this size would appear to be the maximum that fauna underpasses would need to be built in this area to allow use by all native terrestrial fauna.

The goals of the design and maintenance of fauna crossing structures should be twofold: 1. To encourage the maximum number of individuals of the target species to use them and 2. To encourage frequent use, particularly during mating periods. If these two goals can be achieved then the maximum benefit will occur for the populations of that species as the likelihood of gene flow occurring between the populations will be the highest. Based on the results from this study the length of underpasses should be kept to a minimum and vegetation cover near the underpass entrances should be maximised to encourage use by quenda, however, this may have a negative impact on the use by bobtail lizards. This reinforces the conclusions drawn by other authors that the best design for underpasses are likely to be species specific (Clevenger and Waltho, 2000, Taylor and Goldingay, 2003, Lesbarrères *et al.*, 2004, Mata *et al.*, 2008).

Minimising the length of fauna underpasses poses a challenge for road designers as the length of an underpass is almost always determined by the width of the road. One way to overcome this problem could be through the inclusion of vegetated median strips that act as 'stepping stones' between habitat on either side of the road. Rather than have one long underpass connecting the two sides of the road there would be two much shorter underpasses connecting the vegetated median with the surrounding habitat. The amount of vegetation in the median would not need to be large as demonstrated by the frequent use of a 1.0ha patch of habitat by quenda in this study. Taylor and Rohweder (2013) demonstrated that vegetated median strips can be used in this way by sugar gliders (*Petaurus breviceps*) and the results of this study suggest that quenda may be able to use vegetated medians in a similar way.

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Appendix 1. Sample images for fauna using underpasses.

Quenda using underpass 8 at Roe Highway.

Western bobtail lizard using underpass 3 at Paganoni Swamp.

Western grey kangaroo using underpass 1 at Paganoni Swamp.

Brushtail possum using underpass 2 at Paganoni Swamp

Western bluetongue lizard using underpass 5 at Safety Bay.

Southern heath monitor or black headed monitor using underpass 4 at Safety Bay.


Gould's sand monitor using underpass 9 at the Mandurah Entrance Rd.


Dugite using underpass 2 at Paganoni Swamp.


Fox using underpass 6 at Mandogalup.


Cats using underpass 4 at Safety Bay.

Rabbit using underpass 4 at Safety Bay.

Black rat using underpass 8 at Roe Highway.


Pacific black duck and ducklings using underpass 10 at the Mandurah Entrance Rd.

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