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Rock hyrax (*Procavia capensis*) den site selection: preference for artificial sites

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Abstract

Context. Objective assessments of habitat requirements for endangered species are often lacking when planning management strategies, and inappropriate landscape manipulation can sometimes turn an endangered species into a pest. Recent expansive population growth of the rock hyrax *Procavia capensis* in northern Israel has been attributed largely to the proliferation of man-made boulder piles on the fringes of new residential developments.

Aims. The hyrax is a protected species, but when in proximity to residential areas it can be a garden pest and is medically important as a reservoir of cutaneous leishmaniasis. Management should thus consider preservation of hyrax populations in combination with minimising pest potential. We examined the hypothesis that hyraxes prefer artificial boulder piles to natural outcrop crevices as den sites.

Methods. We surveyed all 57 potential den sites in a 1×1 km area around a village in northern Israel, and conducted logistic regression to examine the correlation of hyrax presence with site type (pile or crevice), size, distance from the village, distance from other den sites and network centrality within the den site network. We used the Aikaike information criterion (AIC) to compare logistic models.

Key results. Occupancy was well predicted by site type, site size, and distance from other sites, explaining 59% of the variation in the logistic regression. These three predictors were selected both by considering the combination of predictors that gave the lowest AIC value, and also by the stepwise logistic algorithm.

Conclusions and implications. Hyrax den site preference, and in particular preference for boulder piles over natural crevices, should be integrated into managing this species simultaneously for conservation and pest control in the face of continuing residential encroachment on natural areas.

Additional keywords: anthropogenic landscape changes, habitat selection.

Introduction

Availability of suitable habitat sites is an important ecological parameter in the assessment of the conservation status of endangered species, and in the control of invasive pests (Jonzén 2008). However, objective assessment of what constitutes attractive habitat for a particular species can be problematic. Assessment often begins with a comparison between an animal's requirements for food, shelter, etc., and the availability of such resources in the environment (Morrison *et al*. 2006). Quantitative studies using demographic measures are widely used, particularly for bird populations (Johnson 2007), and can support hypotheses about habitat requirements. Previous studies have correlated presence–absence data with habitat parameters, e.g. for the European lynx *Lynx lynx* (Schadt *et al*. 2002), the yellowhammer *Emberiza citronella* (Bradbury *et al*. 2000) and the red-backed vole *Clethrionomys gapperi* (Orrock *et al*. 2000). When rapid changes in habitat type and distribution occur – for instance as the result of anthropogenic change – the effects, positive or negative, on a focal species can be great (e.g. Howerter *et al*. 2008), and hypotheses should be tested explicitly.

The rock hyrax *Procavia capensis* is a small (~3–4 kg) mammal widespread across Africa and the Middle East, living in groups of 10–50 individuals on rocky outcrops. Hyraxes make their dens in the crevices between rocks, where they are protected from predators, and can avoid the midday heat (Barry and Shoshani 2000). In Israel, the hyrax is a protected species, and is a prominent feature of the native fauna. Over the southern part of the country, hyraxes are in decline (Shalmon 2009), but in the north, despite their protected status, they are also considered pests in residential gardens (Moran 2003). The proximity of hyrax colonies to villages is also of concern because hyraxes serve as reservoirs of cutaneous leshmaniasis (Jacobson *et al*. 2003) and the proliferation of preferred den sites may lead to disease outbreaks (Kershenbaum *et al*., in press).

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Groups working on hyrax ecology and control in Israel have assumed that the proliferation of the species over recent decades in the Galilee region of northern Israel has arisen largely as a result of the construction practices for new residential neighbourhoods; land for housing developments is levelled and cleared by pushing boulders into large piles on the perimeter of villages (Jacobson *et al*. 2003). These piles provide potential den sites for the hyrax, and may be superior to natural crevices because of their greater depth, and because of the existence of multiple entrances with interconnecting subterranean tunnels (Fig. 1). This hypothesis, not previously tested, is examined here using survey data. In addition, we searched for evidence of other factors that might influence den site selection. Because hyraxes move cyclically from site to site over a period of weeks (Kershenbaum, pers. obs.), we examined whether the proximity of neighbouring den sites may also affect occupancy. In addition, since hyraxes forage in residential gardens, we considered whether distance from the perimeter of a village is also a predictor of occupancy. Patch size was tested for correlation with occupancy, to exclude the possibility of detection bias.

Materials and methods

We first identified all potential den sites in a 1×1 km area around the village of Yuvalim in northern Israel. We exhaustively examined a high-resolution (12 cm per pixel) aerial orthophotographic image of the area to identify potential den sites. Sites located within the perimeter of the village were excluded. We then visited each site in the field during February 2009 and determined the presence or absence of hyraxes. Due to the arid nature of the landscape, detection of potential sites was very good, and field inspection did not reveal any additional sites undetected from the aerial image.

We evaluated five potential predictors of hyrax occupation: type of site (boulder pile or crevice) (T), site area (A), distance to the perimeter fence of the village (F), mean distance to all other sites (D) and number of neighbours (K). Our *a priori* expectations were that hyrax occupation would be positively correlated with site area (A) and number of neighbours (K), and negatively correlated with distance to the fence (F) and distance to other sites (D). In addition, we expected to see a stronger preference for boulder piles than crevices.

The distinction between pile and crevice (T) was made on ground inspection: 'pile' patches consisted of rocks and boulders that were not part of the same outcrop piled on top of each other; whereas 'crevice patches' consisted of existing outcrop, and took the form of crevices or small caves (Fig. 1). We determined presence or absence of hyraxes by examining the holes between rocks for hyrax droppings, and recorded a site as 'occupied' if at least one latrine pile was found. Since hyraxes form prominent latrine piles, and droppings decay only slowly in the laboratory (>12 months, pers. obs.), we considered the probability of detection in an occupied site to be very high.

We measured the position and area (A) of each site on the orthophotographic image. Network centrality (K) of a site was defined as the order of that node in the site network, i.e. how many other sites were immediate neighbours of that site.

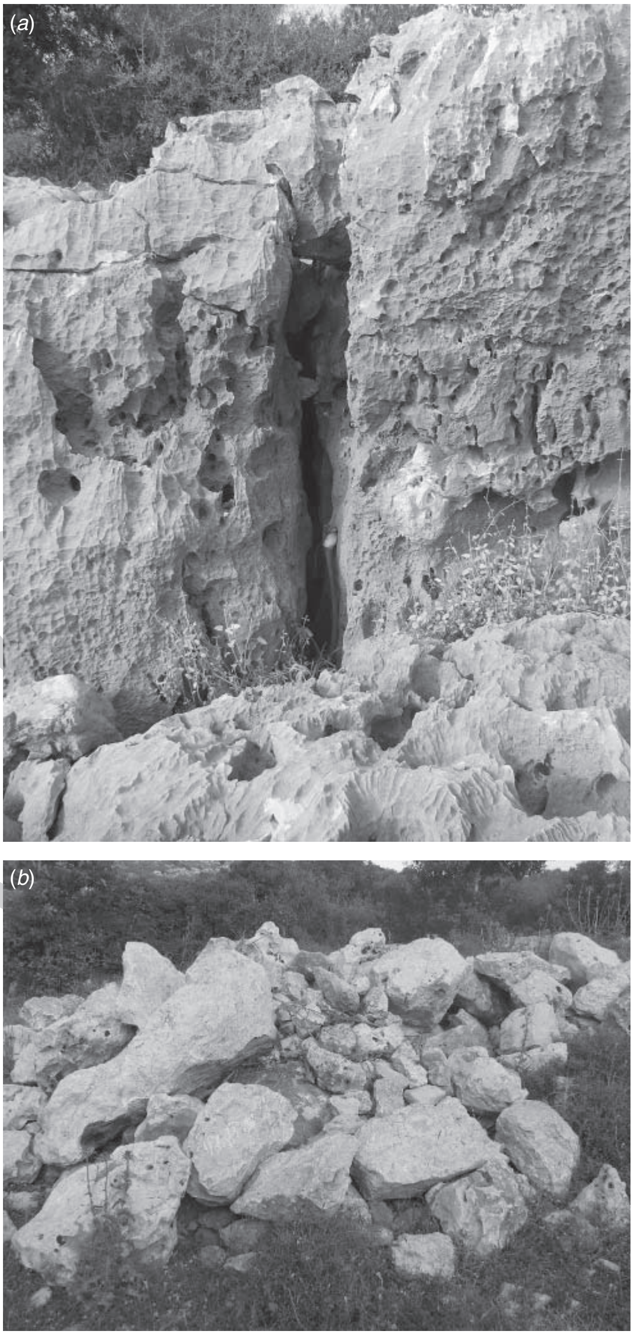

Fig. 1. Different types of hyrax den sites. (*a*) Natural crevice in outcrop and (*b*) artificial loose pile of boulders.

Neighbouring sites were defined as those sharing a common edge in the Delaunay triangulation of the site locations (Preparata and Shamos 1985). For each site, we calculated the mean distance (D) to all other sites from the aerial photograph, as well as the distance to the perimeter fence of the village (F). Of these variables, A and D were log-transformed to normally distributed A' and D'; F and K could not be transformed for normality. We tested all variables for correlation, and performed a Mann–Whitney test for differences in the means between (a) occupied and unoccupied sites, and (b) pile and crevice sites. We calculated the Akaike information criterion (AIC) (Burnham and Anderson 2002) for all 31 combinations of models using the five variables, and in addition, used stepwise logistic regression (SPSS 16.0, Chicago, IL) with the backwards Wald method for the binary output, occupancy. Although stepwise logistic regression in ecology has been criticised (Whittingham *et al*. 2006; Dochtermann and Jenkins 2011) we make use of this only as a confirmation of the AIC analysis.

Results

Of the 57 rock patches identified on the aerial photograph, 18 patches were classified as crevice patches and 39 classified as pile patches. Thirty-one sites (54%) were occupied; 5 (28%) crevice habitats versus 26 (67%) pile habitats were occupied. The spatial distribution of the sites and their Delaunay triangulation is shown in Fig. 2. No correlation was found between the continuous variables (Table 1). Three variables (T, A' and D') were significantly different between occupied and unoccupied sites (Table 2); with artificial sites, larger sites (high A' values), and sites with nearby neighbours (low D' values), more likely to be occupied. Only distance to fence (F) was significantly different between crevice and pile sites, with artificial sites being closer to the perimeter fence than crevice sites (Table 3).

The lowest AIC ($AIC_{min} = 51.28$) of all 31 possible combinations of variables was found for the model using parameters T-A'-D', with $R^2 = 0.59$ (Table 4). Two other models (T-A'-D'-K and T-A'-D'-F) also produced low AIC values, with a Δ_{AIC} ($AIC–AIC_{min}$) of 1.2 and 1.4 respectively. Both had an R^2 of 0.60. The five models with the lowest AIC values are shown in Table 4.

Stepwise logistic regression also yielded the T-A'-D' model as the best predictor of occupancy, which was consistent with the result using the AIC.

In summary, hyrax occupancy was greater in boulder piles, was positively correlated with site area and was negatively correlated with mean distance between sites. Number of neighbours and distance to fence were not significant predictors of occupancy.

Discussion

These results support our hypothesis that the rock hyrax prefers artificial boulder piles over natural rock crevices as den sites. Precedence for safety over foraging sites occurs in other species occupying a similar habitat. For example, alpine marmots *Marmota marmota* prefer rocky habitats to more food-rich open pastures (Borgo 2003), and pygmy rabbits *Brachylagus idahoensis* similarly prefer the safe cover of woody habitats over resource richness (Green and Flinders 1980). The natural habitat of the rock hyrax – crevices in rock outcrops – likely provides less protection from predators and less shade during the midday summer sun than boulder piles, and refuges are isolated from each other, precluding social and mating opportunities while under cover. In contrast, the bulldozing of large boulders produces large interstitial spaces with multiple entrances, interconnected chambers and deep

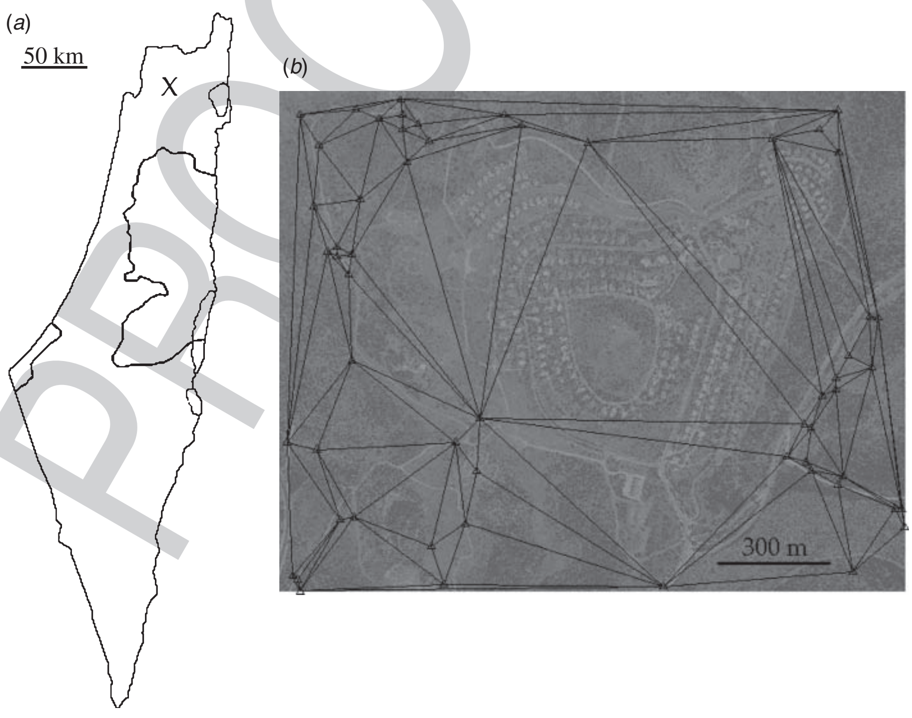

Fig. 2. Location of surveyed dens and their Delaunay triangulation superimposed on the aerial photograph. Location of the survey site is marked with an 'X' on the map to the left.

Table 1. Correlation between the continuous variables
Spearman's rho correlation coefficient (ρ) and significance ($n = 57$)

		A'	F	D'	K
Log area (A')	ρ	–	0.056	–0.127	0.094
	sig.	–	0.679	0.348	0.487
Distance to fence (F)	ρ	–	–	0.123	–0.096
	sig.	–	–	0.361	0.478
Log mean distance to all other sites (D')	ρ	–	–	–	–0.143
	sig.	–	–	–	0.288
Number of neighbours (K)	ρ	–	–	–	–
	sig.	–	–	–	–

Table 2. Results of Mann–Whitney test ($n = 26$, 31) for difference between sites with and without hyraxes
Significance is for an asymptotic 2-tailed test

Variable	Symbol	Z	p
Type	T	–2.716	0.007
Log area	A'	–2.724	0.006
Distance to fence	F	–1.426	0.154
Log mean distance to all other sites	D'	–3.701	>0.001
Number of neighbours	K	–1.520	0.128

Table 3. Results of Mann–Whitney test ($n = 18$, 39) for difference between crevice and pile sites
Significance is for an asymptotic 2-tailed test

Variable	Symbol	Z	p
Log area	A'	–0.773	0.440
Distance to fence	F	–2.575	0.010
Log mean distance to all other sites	D'	–0.069	0.945
Number of neighbours	K	–0.274	0.784

resting sites. These features of rocky refuges are also preferred by other species. For example, the brush-tailed rock-wallaby *Petrogale penicillata* prefers rocky sites with caves and overhangs, which provide greater protection from predators (Short 1982).

Other factors, such as the proximity to high quality forage in irrigated residential gardens, rather than (or in addition to) their artificial nature, may also make artificial rock piles attractive. By considering several potential factors, our analysis indicates that artificial sites consisting of boulder piles are preferred by hyraxes, independent of the distance from the village perimeter. We also showed that the proximity to other den sites is a significant factor in den site choice.

Our examination of all 31 combinations of predictors showed that the T-A'-D' model performed best according to the AIC. However, two other models (T-A'-D'-K and T-A'-D'-F) produced AIC values within 2 of the best AIC value. Burnham and Anderson (2002) suggest that models with a Δ_{AIC} less than 2 should be considered when drawing inferences; however, both of these alternative models consisted of the T-A'-D' model with the addition of an extra variable (F or K), and this explained only an extra 1% of the variance over the T-A'-D' model. Thus, when considering the predictors of site occupation, there is no justification for including variables F and K in the model. Repeating this analysis using stepwise logistic regression confirmed these results.

We conclude that the construction of boulder piles provides a preferred habitat for the rock hyrax, which is consistent with our understanding of hyrax ecology. Larger sites, and sites that are less isolated are also preferred. However, since there is no significant difference in the size or isolation between crevice (natural) and boulder pile (artificial) sites, this appears to be a random effect unrelated to the origin of the site. Thus, artificial boulder piles are likely to be an important resource for sustaining hyrax populations.

In sharp contrast to their decline in the southern Negev desert (Shalmon 2009), hyrax populations have been increasing in northern Israel over recent decades. Among the explanations put forward to explain this are the proliferation of artificial den sites, reduced distances among sites to allow migration, and the proliferation and increased availability of nearby residential gardens with high quality forage. While not directly supporting the former hypothesis, that boulder pile proliferation leads to increased hyrax population size, our findings show that these sites are favoured by hyraxes, and therefore may positively affect population size. In this case, anthropogenic landscape changes have produced an 'oasis effect', supporting populations of wild animals, rather than reducing them (Bock *et al.* 2008). The relevant authorities can use this information when planning control strategies and conservation efforts. Specifically, not allowing boulder piles to remain near villages may reduce garden pests and disease transmission threats and building or managing boulder piles in

Table 4. Results of the logistic regression for different statistical models: the five models with the lowest AIC values are shown
Three variables, T, A', and D' appear in the four lowest AIC models. Addition of other parameters F and K have only a minor effect on the R^2 value

Type (T)	Distance to fence (F)	Number of neighbours (K)	Log area (A')	Log mean distance to other sites (D')	# of parameters	AIC	Δ_{AIC}	R^2
√	×	×	√	√	3	51.275	0	0.595
√	×	√	√	√	4	52.494	1.219	0.602
√	√	×	√	√	4	52.631	1.356	0.600
√	√	√	√	√	5	54.057	2.782	0.607
√	×	×	×	√	2	54.304	3.029	0.523

more remote areas may support population viability while reducing conflict with humans.

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