Experimental Rock Outcrops Reveal Continuing Habitat Disturbance for an Endangered Australian Snake

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Abstract: *Protected areas are commonly viewed as safe havens for endangered species. To test this notion, we experimentally constructed small rock outcrops for the endangered broad-headed snake (*Hoplocephalus bungaroides*) within a national park near Sydney, Australia. Rock outcrops provide vital shelter sites during the cooler months of the year. Constructed rock outcrops (3 × 5 m) were placed at 11 paired sites located near (≤250 m) and far from (>400 m) walking tracks and roads. Eight of our 22 rock outcrops were disturbed by people over a 15-month period. Disturbance consisted of displacement of some rocks or complete destruction of the outcrop. Disturbed outcrops occurred up to 450 m from a walking track or road. Disturbance to natural outcrops has also been observed in this park. This demonstrates a continuing decline in the quality of this snake's habitat. Twenty of our rock outcrops were colonized by velvet geckos (*Oedura lesueurii*), the primary prey of this snake. One broad-headed snake was found in one outcrop. According to these findings, attempts to restore the habitat of this endangered snake should be centered on sites located ≥500 m from a walking track or road. Our study highlights the value of targeted experiments that precede larger-scale habitat restoration.*

Farallones de Roca Experimentales Revelan la Perturbación Continua del Hábitat para una Serpiente Australiana Amenazada

Resumen: *Las áreas protegidas son comúnmente vistas como paraísos libres de riesgos para las especies amenazadas. Para probar esta noción, construimos experimentalmente pequeños farallones rocosos para la serpiente amenazada de cabeza ancha (*Hoplocephalus bungaroides*) dentro de un parque nacional cercano a Sydney, Australia. Los farallones de roca proveen protección vital durante los meses más fríos del año. Los farallones construidos (3 × 5 m) fueron colocados en once sitios pareados localizados cerca (≤250 m) y lejos (>400 m) de los senderos y carreteras. Ocho de los 22 farallones fueron perturbados por gentes sobre un período de 15 meses. La perturbación consistió en el desplazamiento de algunas rocas o en la completa destrucción del farallón. Los farallones perturbados se encontraban hasta 450 m de los senderos o las carreteras. La perturbación de farallones naturales también ha sido observada en este parque. Esto demuestra una disminución continua de la cantidad de este tipo de hábitat para las serpientes. Veinte de nuestros farallones fueron colonizados por gecos velvet (*Oedura lasueurii*), la principal presa de esta serpiente. Con base en estos resultados, los intentos para restaurar el hábitat de esta especie de serpiente amenazada deberán centrarse en sitios localizados ≥500 m de los senderos o las carreteras. Nuestro estudio subraya el valor de los experimentos que preceden a esfuerzos de restauración del hábitat a gran escala.*

Introduction

A common approach to conservation has been the establishment of protected areas (Noss et al. 1997; Primack 1998), and as conservation of endangered species has received more attention, reliance on protected areas has become more pronounced. In developed countries, it is commonly assumed that endangered species contained within protected areas will require minimal management because the factors responsible for their decline are unlikely to extend into protected areas. This assump-

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tion may save resources but should be tested whenever it is made.

The broad-headed snake (*Hoplocephalus bungaroides*) is a small elapid endemic to the sandstone habitats within a 150-km radius of Sydney, Australia (Shine et al. 1998). Within this range are many protected areas, but there is little information on this species' distribution therein (Cogger et al. 1993). It is well documented that extensive areas of habitat have been lost to urbanization outside these protected areas (Cogger et al. 1993; Shine et al. 1998). This snake has been listed as endangered since 1974 (Hersey 1980) but has only been the subject of detailed research in the last few years, possibly because venomous snakes attract little public sympathy.

The primary cause of the decline of the broad-headed snake is believed to be the removal of loose rock that provides vital shelter sites during late autumn to early spring (Shine et al. 1998; Webb & Shine 1998). Loose sandstone rocks are highly valued for garden ornamentation around Sydney, and collection for this purpose is believed to be the main cause of rock removal (Hersey 1980; Shine & Fitzgerald 1989; Schlesinger & Shine 1994; Mahony 1997; Shine et al. 1998). A recent study within a protected area documented human disturbance of the rock habitat and detected broad-headed snakes more commonly away from roads and walking tracks (Goldingay 1998). This raises two important questions: (1) is habitat disturbance an ongoing process in a protected area and (2) does distance from roads and tracks determine the likelihood of disturbance? These questions have important implications for attempts to restore the loose rock habitat, and they highlight the need to conduct preliminary restoration experiments before extensive restoration is attempted.

Methods

Our study was conducted in Royal National Park (lat 34°05′S, long 151°05′E), which has an area of approximately 17,000 ha and forms the southern boundary of the Sydney metropolitan area. Continuing urbanization has virtually isolated the park from other bushland areas.

We selected sites near (≤250 m) and far from (>400 m) roads and walking tracks to test the hypothesis that sites located close to rather than far from roads and walking tracks incur more disturbance. Only sites with a north to west aspect were considered because broad-headed snakes prefer sites that receive the afternoon sun (Shine et al. 1998; Webb & Shine 1998). Eleven paired rock sites consisting of one near and one far were chosen at random from 22 paired sites in a sequence from north to south across the park. Sites within a pair were located no closer than 0.5 km apart and contained similar habitat. We constructed an experimental rock outcrop at each site on a rock platform wide enough to accommodate a 3 × 5 m quadrat, sufficiently flat to allow rocks to be positioned easily, and devoid of loose rock.

Each quadrat was marked out into 50-cm squares with a chalk string line to enable mapping of placed rocks. Ten rocks were chosen from the surrounding area for placement within each quadrat (Fig.1). This density of rocks and the relatively small size of the quadrat were chosen to mimic the density of loose rocks at sites occupied by broad-headed snakes. Rocks were used only if found on bare earth and if they were not being used by vertebrates. Rocks were 15–90 cm long, 10–15 cm wide, and 3–11 cm thick. These dimensions are used by broad-headed snakes and their gecko prey (Schlesinger & Shine 1994; Goldingay 1998; Shine et al. 1998; Webb &

Figure 1. Experimental rock outcrop showing 10 rocks placed within a 3 × 5 m quadrat. The boundary tape was removed after outcrop establishment.

Shine 1998). Rocks that were relatively flat on the underside were preferentially chosen to create a narrow gap for rock-dwelling reptiles.

The length, width, and thickness of all rocks used ($n = 220$) were measured. There was no difference between the dimensions of the rocks used at the near sites and those at the far sites (length: $t = 1.06$, $p = 0.29$; width: $t = 0.25$, $p = 0.80$; thickness: $t = 0.16$, $p = 0.88$). The rocks were placed within the quadrat so as to fit tight with the substrate and to be stable when touched on any edge. This took 5–10 minutes per rock and led to the placement of rocks within the quadrat being determined by the surface of the rock platform, which approximated random placement. Rocks were placed the same way up as they had been found originally, except for two rocks that had to be inverted to fit tightly. Each quadrat was then carefully mapped on a data sheet and photographed. A small cream-colored mark was painted in two diagonally opposite corners to facilitate the replacement of the quadrat grid during monitoring of the experiment.

Sites were visited a mean of 4.5 times between May 1998 and August 1999, with individual paired sites usually visited together. We made multiple visits to increase the chance of detecting snakes at the sites and to allow us to reconstruct outcrops that had been disturbed so that we could consider disturbance frequency. During each visit, the photos and maps of each site were checked to determine whether rocks had been displaced. Each rock was then lifted carefully to determine whether it was being used by reptiles. If rocks had been displaced, they were returned to their original position. If damaged, new rocks were found and placed.

Results

Eight of the 22 experimental rock outcrops showed evidence of human disturbance (Table 1). The level of disturbance to the placed rocks varied from a single rock being moved at one site (site 9), to rocks being placed in a pile (site 14), to all rocks being thrown off the platform at four sites (sites 5, 6, 7, 11). In the latter case, smashed rocks were observed on the ground below the platform. Our multiple visits and outcrop reconstruction revealed that at two sites rocks were initially displaced from the position of placement but later were totally removed.

The disturbance of the outcrops was independent (G test; $G = 0.79$; $p > 0.25$) of our categorization of sites based on proximity to roads and tracks, although more near sites were disturbed. At least some rocks were left in place at the far sites that were disturbed. Moreover, the sites in the far category that were disturbed were closer (<500 m) to a road or track than most others in this category. When sites were placed in categories of ≤450 m and ≥500 m from a road or track, disturbance was dependent on distance from tracks and roads (Fisher exact test; $p = 0.02$) because disturbance did not occur in the ≥500-m distance category.

Seventy-five percent of damaged sites were accessed from a walking track (Table 1). Although sites were not established to test the influence of the type of access to a site, we found that 46% of sites accessed from a track were damaged, whereas 22% of sites accessed from a road were damaged.

A large proportion (91%) of the outcrops was colonized by velvet geckos (*Oedura lesueurii*), the primary prey of the broad-headed snake. All outcrops at far sites were colonized, whereas two in the near sites were not (Table 1). The number of geckos recorded in the outcrops was variable but showed no difference among near and far sites (Mann-Whitney test; $U = 74$, $p > 0.2$).

Snakes were found sheltering under the loose rocks at three of the undisturbed sites. This included a broad-headed snake at one site, the small-eyed snake (*Rhinoplocephalus nigrescens*) at two sites, and a green tree snake (*Dendrelaphis punctulata*) at one site (Table 1). The small-eyed snakes were present during two different visits.

Discussion

Our results suggest that protected areas may provide inadequate protection for endangered species that require specialized habitat components subject to human disturbance. Earlier studies have focused on the removal of loose rocks for garden ornamentation as the main threat to the broad-headed snake (Hersey 1980; Shine & Fitzgerald 1989; Schlesinger & Shine 1994; Shine et al. 1998; Webb & Shine 1998). Our study suggests that on-going disturbance to the loose rock habitat that is not associated with rock collection may also pose a substantial threat to the persistence of this snake, even within a well-patrolled national park. Within Royal National Park, visitors are handed brochures that state that rock formations as well as fauna and flora are protected, and hikers are urged to remain on existing walking tracks. Fines of up to $300 can be imposed for a variety of offenses.

The displacement of loose rocks from our rock outcrops could have been caused only by humans. Rocks were placed in a pile at one site, some were smashed on the platform from considerable force at two other sites, and many or all were thrown from the platform to the ground 3–10 m below at four sites, again requiring considerable force. Even where rocks were overturned, the movement of these rocks was not consistent with interference by the wallabies (*Wallabia bicolor*) or introduced rusa deer (*Cervus timorensis*) that occur in the park and are the only other likely cause of rock disturbance. The different types of disturbance listed above suggest different motives by humans for rock displacement.

Table 1. Disturbance and colonization of experimental rock outcrops.

Site[a]	*Access*[b]	*Distance (m)*[c]	*Geckos*[d]	*Snakes*[e]	*Disturbance events*[f]
Near					
1	track	40	1	—	—
2	road	120	1	—	—
3	road	90	9	—	—
4	road	250	2	—	—
5	road	100	3	—	all rocks thrown off platform
6	track	130	0	—	all rocks thrown off platform (six broken)
7	track	20	3	—	four rocks overturned; all rocks smashed or thrown off platform
8	track	60	2	—	—
9	track	1	0	—	one rock overturned and one rock moved; one rock moved
10	road	200	3	—	—
11	track	15	1	—	one rock thrown; one rock smashed; three rocks removed and one moved; all rocks thrown (nine smashed)
Far					
12	track	600	2	—	—
13	road	600	1	H, R	—
14	track	450	3	—	eight rocks placed in a pile adjacent to the platform
15	road	400	4	—	—
16	road	400	2	—	two rocks overturned
17	track	400	3	—	six rocks thrown off platform
18	track	900	3	D	—
19	road	600	1	—	—
20	track	500	6	—	—
21	road	600	1	R	—
22	track	600	2	—	—

[a]*Sites placed into distance categories based on proximity (≤250 m [near], ≥400 m [far]) to roads and walking tracks.*
[b]*Access indicates whether the point of access to a site was from a road or walking track.*
[c]*Distance to nearest track or road.*
[d]*The maximum number of geckos recorded at a site during a visit.*
[e]*H,* Hoplocephalus bungaroides*; R,* Rhinoplocephalus nigrescens*; D,* Dendrelaphis punctulata.
[f]*A semicolon separates different events.*

Broad-headed snakes are highly selective in their choice of rocks based on rock thermal properties (Webb & Shine 1998), and even simple overturning of such rocks may alter these properties. Surveys in six other protected areas north of Sydney documented substantial degradation of loose rock habitat arising from causes not associated with rock collection for gardens (D.A.N & R.L.G., unpublished data). Despite this snake being listed as endangered in 1974, it appears to have been greatly overlooked for management.

Our rock outcrops may have attracted vandalism because they were mostly surrounded by bare rock. We took great care to ensure that our outcrops were not identified in any way that would attract people to these sites. The clumped nature of the rocks would not have been apparent until a person was standing close to the outcrop. Therefore, we believe that we measured disturbance events that would be directed at natural outcrops. This disturbance was not confined to one location but occurred throughout the park.

Our results are generally consistent with the prediction that disturbance events are more likely to occur at sites located close to roads and walking tracks (Schonewald-Cox & Buechner 1992; Matlack 1993). Many outcrops close (≤250 m) to roads and tracks were damaged. Four outcrops were totally destroyed, and multiple disturbance events occurred at two of these and one other site. Three outcrops located at a distance (450 m) from a road or track were also damaged, although only one had rocks removed from it. These observations suggest that 450 m could be viewed as a maximum disturbance distance to guide management activities. Also, it appears that access to rock outcrops from walking tracks, rather than from roads, may lead to more frequent disturbance, although this requires further study.

Our study provides information for use in restoring the habitat of the broad-headed snake and demonstrates the value of preliminary habitat-restoration experiments. Most (91%) of the rock outcrops were colonized by velvet geckos, which are the primary prey of the broad-headed snake (Webb & Shine 1998). This is important, because Shine et al. (1998) showed empirically that the number of broad-headed snakes found in an area is positively related to the abundance of these geckos. Geckos occurred at a relative frequency of 0.24 per rock across the 22 experimental outcrops, compared with 0.23 per rock (based on the maximum number of geckos recorded per site and rocks on a rock substrate) across 26 natural outcrops surveyed by Goldingay (1998). The single broad-headed snake found sheltering in one of our experimental outcrops represents 0.01 snakes per rock and compares to 0.02 broad-headed snakes per rock recorded by Goldingay (1998). These observations suggest that it may be relatively easy to attract sufficient prey for broad-headed snakes to a site. Thus, habitat restoration should be achievable, but restored sites distant (≥500 m) from roads and walking tracks are likely to incur the least disturbance.

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Literature Cited

Cogger, H. G., E. E. Cameron, R. A. Sadlier, and P. Eggler. 1993. The action plan for Australian reptiles. Australian Nature Conservation Agency, Canberra, Australian Capital Territory.

Goldingay, R. L. 1998. Between a rock and a hard place: conserving the broad-headed snake in Australia's oldest National Park. Proceedings of the Linnean Society of New South Wales **120:**1–10.

Hersey, F. 1980. Broad-headed snake *Hoplocephalus bungaroides.* Pages 38–40 in C. Haegl, editor. Endangered animals of New South Wales. National Parks & Wildlife Service, Sydney.

Mahony, S. 1997. Efficacy of the "threatening processes" provisions in the Threatened Species Conservation Act 1995 (NSW): bush-rock removal and the endangered broad-headed snake. Environmental and Planning Law Journal **14:**3–16.

Matlack, G. R. 1993. Sociological edge effects: spatial distribution of human impacts in suburban forest fragments. Environmental Management **17:**829–835.

Noss, R. F., M. A. O'Connell, and D. D. Murphy. 1997. The science of conservation planning: habitat conservation under the Endangered Species Act. Island Press, Washington, D.C.

Primack, R. B. 1998. Essentials of conservation biology. Sinauer Associates, Sunderland, Massachusetts.

Schlesinger, C. A., and R. Shine. 1994. Choosing a rock: perspectives of a bush-rock collector and a saxicolous lizard. Biological Conservation **67:**49–56.

Schonewald-Cox, C., and M. Buechner. 1992. Park protection and public roads. Pages 373–395 in P. L. Fiedler and S. K. Jain, editors. Conservation biology: the theory and practice of nature conservation, preservation and management. Chapman and Hall, New York.

Shine, R., and M. Fitzgerald. 1989. Conservation and reproduction of an endangered species: the broad-headed snake, *Hoplocephalus bungaroides* (Elapidae). Australian Zoologist **25:**65–67.

Shine, R., J. Webb, M. Fitzgerald, and J. Sumner. 1998. The impact of bush-rock removal on an endangered snake species, *Hoplocephalus bungaroides* (Serpentes: Elapidae). Wildlife Research **25:**285–295.

Webb, J. K., and R. Shine. 1998. Using thermal ecology to predict retreat-site selection by an endangered snake species (*Hoplocephalus bungaroides*: Serpentes, Elapidae). Biological Conservation **86:**233–242.