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Paving the way for habitat restoration: can artificial rocks restore degraded habitats of endangered reptiles?

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Abstract

The addition of artificial resources (nest boxes, shelter sites) to degraded habitats may help reverse the decline of species that rely on these structures. In south-eastern Australia, the endangered broad-headed snake (*Hoplocephalus bungaroides*) and its major prey, the velvet gecko (*Oedura lesueurii*), use exposed sandstone rocks for diurnal shelter sites. Removal of these sandstone "bush-rocks" for landscaping urban gardens has contributed to the decline of both species, and recent studies suggest that rock removal affects broad-headed snakes indirectly, via a decline in prey numbers. Thus, one way to restore degraded sandstone habitat is to provide artificial rocks for the snakes' major prey, the velvet gecko. To investigate this possibility, we placed 128 square concrete pavers (19 cm wide, 5 cm thick) at three study sites in Morton National Park, where velvet geckos and broad-headed snakes are relatively common. We manipulated crevice width (4 vs 8 mm) and temperature of concrete pavers (shaded vs exposed) to determine how these factors influence retreat-site selection by velvet geckos. We monitored the usage of these artificial habitats by geckos and invertebrates over a 1-year period. During the cooler months most velvet geckos selected exposed pavers with narrow crevices. Larger geckos used wider crevices than did smaller conspecifics. Our results show that habitat restoration with appropriate-sized concrete pavers may be a feasible conservation technique for degraded rock outcrops. We recommend the use of large pavers (30–45 cm wide, 5–10 cm thick) with a variety of crevice sizes (up to 10 mm) to maximize the diversity of retreat-sites for broad-headed snakes and saxicolous lizards. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Habitat restoration; Reptiles; Bush-rock; Thermal ecology; Snakes

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1. Introduction

Habitat destruction is the major cause of endangerment for many of the world's threatened species (Losos et al., 1995; Fahrig, 1997). Taxa that rely upon specific components of the habitat are at particular risk, especially if destruction of these habitats offers financial rewards to local people (e.g. Mittermeier et al., 1992). This process appears to have contributed to the decline of a small nocturnal elapid snake, the broad-headed snake (*Hoplocephalus bungaroides*), in south-eastern Australia. Broad-headed snakes use sandstone rocks as diurnal retreat-sites, and widespread removal of these "bush-rocks" for landscaping urban gardens has long been blamed for the snake's decline (Krefft, 1869; Hersey, 1980; Shine and Fitzgerald, 1989). In many areas bush-rock removal has been so severe that habitat restoration may be the only way to reverse existing declines (Webb and Shine, 1998a). However, habitat restoration projects can be problematic, particularly if they do not identify which components of the "habitat destruction" have played a causal role in the declines (e.g. Simberloff, 1987; Dolman and Sutherland, 1994; Caughley and Gunn, 1995).

Recent ecological studies have shown that juvenile *H. bungaroides* prey chiefly on velvet geckos (*Oedura lesueurii*) (Webb and Shine, 1998b). During the cooler months velvet geckos and broad-headed snakes use thermally suitable sandstone rocks as diurnal retreat-sites (Webb and Shine, 1998a,c), and these rocks are targeted by bush-rock collectors (Schlesinger and Shine, 1994a,b; Webb, 1996; Shine et al., 1998). Path analysis suggests that rock removal affects the snakes indirectly, via a decline in prey numbers; that is, areas which support low numbers of geckos (due to rock removal)

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support fewer broad-headed snakes (Shine et al., 1998). Thus, any attempt to restore the habitat of *H. bungaroides* needs to focus on the needs of both predators and prey.

The obvious way to restore degraded sandstone habitats is to replace the rocks that have been removed. However, this is not a straight-forward task. Natural rocks vary considerably in size, shape, and thickness, and only form crevices suitable for broad-headed snakes at the original location where they weathered from the underlying rock substrata (Webb, 1996). Furthermore, replacement of natural rocks is not feasible because it involves purchasing either: (a) bush-rock, and thereby encouraging the commercial activity that created the original problem; or (b) quarried sandstone, which is expensive and equally attractive to rock thieves. One solution to this dilemma is to use cheap, unattractive artificial "rocks", such as concrete pavers (Webb and Shine, 1998a). However, we need to know (1) whether or not artificial rocks will actually be used by the animals; and (2) if so, what kinds of rocks will be most effective in this respect. Because snake numbers appear to depend upon gecko abundance rather than rock availability per se (Shine et al., 1998), our focus is on the lizards rather than the snakes. To determine the feasibility of habitat restoration, we investigated whether artificial rocks (concrete pavers) would be used as retreat-sites by the velvet gecko (*O. lesueurii*).

Field studies suggest that velvet geckos select rocks on the basis of crevice size (Schlesinger and Shine, 1994b) and temperature (Webb and Shine, 1998a). We manipulated both of these factors for 128 concrete pavers and monitored the subsequent recruitment of vertebrates and invertebrates under them. Rather than placing pavers in areas where bush-rock had been removed (where prey and predator populations will be low: Shine et al., 1998), we placed pavers in undisturbed sites in Morton National Park. If the animals use artificial rocks in an area where "better" natural rocks are abundant, then the approach should be even more effective in areas where few natural rocks remain.

2. Materials and methods

2.1. Study sites

This study was part of a 4-year radio-telemetry and mark-recapture study of *H. bungaroides* and *O. lesueurii* (Webb, 1996). Our field experiment was carried out at three study sites, each > 1 km apart, on the western edge of a sandstone plateau (400 m elevation) in Morton National Park (160 km south of Sydney, NSW, Australia). Detailed descriptions of these sites and our general field methods are provided elsewhere (Webb and Shine, 1997a,b). The experiment began during November 1994, and was terminated in February 1996 when vandals threw pavers over the cliffs.

2.2. Effects of crevice size, shading, and placement of pavers

Artificial rocks consisted of square, gray, concrete pavers (19 cm wide, 5 cm thick). We manipulated crevice size by gluing four small pieces of wood (4 or 8 mm thick) onto the corners of each paver. When placed on a flat surface the pavers provided a minimum crevice width of either 4 or 8 mm, but irregularities in natural rock substrata meant that maximum crevice widths often exceeded this size in the field. Four pavers (two narrow, two wide crevices) were placed 20 cm apart in a square formation, with placement of crevice size randomised, on areas of flat, exposed bare rock outcrop. Groups of four pavers were spaced at least 5 m apart (occasionally further, depending on site topography), and were placed 5 m from the cliff edge. We chose this distance because most natural rocks used by geckos and snakes are relatively close (< 10 m) to the cliff edge and hence, to alternative retreat-sites (cliff top crevices: Webb and Shine, 1998a). We numbered each paver with a white paint pen and placed them on study sites between 18 November 1994 and 11 January 1995 (Table 1). To assess the effects of temperature on rock use, we shaded half the pavers at each site. We used artificial shaders to create uniform shade, and thus, similar temperatures, under "shaded" pavers. Artificial shaders consisted of square steel frames (90 cm wide×50 cm high) covered with two layers of 75% beige shade cloth. Each shader was large enough to shade a group of four pavers, and was held in position by wiring two bricks onto the steel frame. Control shaders (square steel frames) were placed over the remaining exposed pavers.

2.3. Thermal characteristics of shaded vs exposed pavers

We measured temperatures under one shaded and one exposed paver with wide crevices by gluing thermocouples onto the underside (middle) of each paver (T_u), and the substratum directly below (T_s). Temperatures were recorded every 20 min with a Campbell CR10 Data Logger (Campbell Scientific, Utah, USA). Temperatures under eight natural rocks were recorded at the same time (see Webb and Shine, 1998a for full details). We recorded paver temperatures during summer (December 1994–February 1995), but vandalism to this site forced us to abandon collection of thermal data (due to risk of losing expensive data loggers). However, the high correlation between temperatures under pavers and rocks of similar thickness and degree of shading (see Results) allowed us to use our extensive data on rock temperatures (> 24 months data for 1993–1994) to

Table 1
The number of different pavers used by animals at each study site during each sampling period[a]

Sampling date	Study site Site 1 (44)	 Site 2 (32)	 Site 4 (52)	Predicted daytime temperatures Exposed pavers	 Shaded pavers
11 April 1995	5	1	11	24.7 (12.9–34.6)	21.8 (14.0–25.4)
2 May 1995	12	Disturbed	18	23.6 (15.8–31.0)	20.2 (16.3–22.6)
16 May 1995	9	12	Disturbed	20.1 (10.1–31.3)	15.8 (11.2–20.2)
14 August 1995	Disturbed	Disturbed	Disturbed	14.5 (11.0–20.8)	13.1 (10.5–16.8)
2 September 1995	9	Disturbed	Disturbed	21.1 (8.3–32.6)	17.5 (9.5–22.8)
13 November 1995	9	1	3	28.2 (14.8–41.7)	24.0 (16.5–29.6)
Proportion of total	45.5%	40.6%	50.0%		

[a] The total number of pavers placed at each site shown in parentheses (note that four shaded pavers from sites 1 and 4 were removed by vandals). Not all study sites could be sampled at the same time due to human disturbance at some of the sites. The bottom line of the table shows proportion of all pavers used by animals at each site during the experiment. Predicted daytime (07.00–19.00 h) temperatures (mean and range) under exposed and shaded pavers are shown for each sampling period, based on temperatures recorded under two rocks (20–30 cm wide, 4 cm thick) on two sunny days (for each sampling date) during 1994.

predict mean and maximum temperatures under shaded and exposed pavers throughout the year.

2.4. General protocol

A total of six sampling trips were carried out during 1995 (Table 1). At each site we noted the position of artificial shaders, and recorded the number of vertebrates and invertebrates under each paver. Velvet geckos were measured (snout-vent length, tail length), sexed, visually assessed for reproductive status (adult males have large testes and spurs; eggs are visible inside gravid females) and individually marked with a unique toe-clip. Human disturbance was a common occurrence, and resulted in overturned pavers or shaders, or both, and occasionally, loss of pavers (four shaded pavers at sites 1 and 4 were removed by vandals). We did not use data for disturbed sites; in these instances we placed pavers and shaders back into their original positions. Thus, sample sizes in the final data set varied among sites (Table 1).

3. Results

3.1. Thermal characteristics of shaded versus exposed pavers

Shading significantly altered the thermal profiles of pavers (Fig. 1). On clear days during summer, maximum temperatures of exposed pavers (T_u) and the substratum directly below (T_s) were often 15 and 9°C higher than those of shaded pavers (Fig. 1). We compared temperatures of shaded and exposed pavers (T_u) and the substratum directly below (T_s) during five sunny days in December 1994. One-factor ANOVAs revealed that mean and maximum temperatures (T_u) of the exposed paver and the substratum directly below (T_s) were significantly higher than those of the shaded paver (T_u: mean of 31 vs 26.4°C, $F_{1,8}=12.7$, $p < 0.01$; maximum of 49.3 vs 34.4° C, $F_{1,8}=102.1$, $p < 0.0001$; T_s: mean of 30.6 vs 26.4°C, $F_{1,8}=9.0$, $p = 0.02$; maximum of 41.5 vs 32.7°C, $F_{1,8}=45.2$, $p = 0.0001$). Minimum temperatures were similar under exposed and shaded pavers (for T_u: means of 19.1 vs 20.6°C, for T_s means of 22.3 vs 22.0°C).

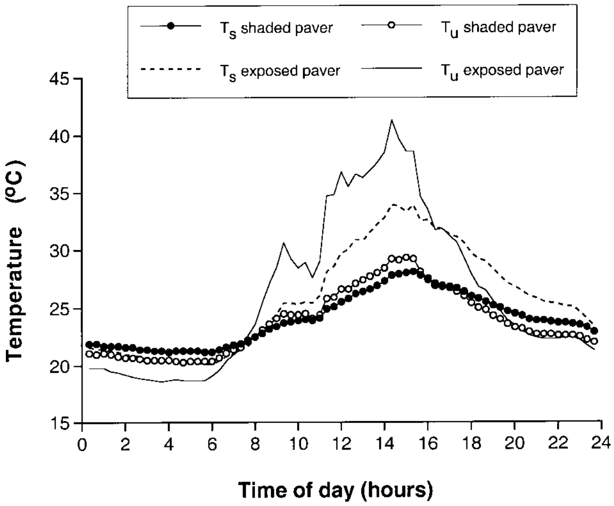

Fig. 1. Daily cycle of temperatures under pavers (T_u, open symbols and solid line) and the substratum directly below (T_s, solid symbols and dotted line) for exposed (lines) and shaded (circles) pavers during a sunny summer day (18 January 1995). Temperatures were recorded every 20 min using a Campbell CR10 data logger.

3.1.1. Thermal profiles of natural rocks versus pavers

Were thermal profiles of concrete pavers similar to those of natural rocks? Because rock temperatures are largely determined by rock thickness and degree of shading (Huey et al., 1989; Webb and Shine, 1998a), we compared thermal profiles of two rocks (20–30 cm wide, 4 cm thick) with those of the pavers. We used a two-factor ANOVA, with rock type (paver vs rock) and shading (exposed vs shaded) as the two factors, and single temperatures (mean and maximum T_u and T_s) from each of five sunny days (December 1994) as data points. For all analyses, there was no effect of rock type, and interactions between the two factors were not significant. In contrast, the effect of shading was highly significant (e.g. for mean T_u: $F_{1,16} = 15.5$, $p = 0.001$; mean T_s: $F_{1,16} = 10.1$, $p = 0.006$). Thus, thermal profiles of rocks and pavers with the same degree of shading were very similar on different days, but shaded rocks and pavers were significantly cooler than those in exposed locations. Temperatures of pavers were highly correlated with those of rocks of similar thickness (e.g. correlation between T_s of rock and paver on a sunny day, $r^2 = 0.99, p < 0.0001$). Thus, we used our 1994 temperature data for two rocks (20–30 cm wide, 4 cm thick, in shaded and exposed locations) to predict paver temperatures for our sampling dates in 1995. We used data for two sunny days each month to predict paver temperatures (mean, range) during our sampling trips (Table 1).

3.2. *Effects of shading and crevice size on paver usage*

The number of pavers used by animals at each site for each sampling date is shown in Table 1. Human disturbance prevented us from gathering data on numerous occasions. Despite this, a high proportion (40–50%) of pavers was used by animals at each study site (Table 1). To determine whether paver usage differed between sites, we used a two-factor ANOVA, with sites and shading as the two factors, and numbers of individual pavers as data points. This analysis revealed no difference between the sites ($F_{2,6} = 1.03, p = 0.41$), but exposed pavers were used significantly more often by animals than were shaded pavers ($F_{1,6} = 7.40, p = 0.03$). The interaction between the two factors was not significant ($F_{2,6} = 1.20, p = 0.36$); that is, animals used exposed pavers more frequently than shaded pavers on all three study sites. Did animals select pavers on the basis of crevice size? A two-factor ANOVA (with shading and crevice size as the two factors) confirmed that paver use was affected not only by exposure (exposed pavers were used more often than shaded pavers, as shown above: $F_{1,8} = 12.65, p = 0.007$), but also by crevice size. Pavers with small crevices were used significantly more often than pavers with wide crevices ($F_{1,8} = 9.29, p = 0.02$). The interaction between these factors was not significant ($F_{1,8} = 0.58, p = 0.47$); that is, pavers with small crevices were used more often than those with wide crevices, regardless of whether or not the paver was shaded.

Table 2
Number of different taxa recorded under each type of paver during autumn and spring[a]

Animals recorded	Paver type: Shaded ($n = 60$) Narrow	Shaded ($n = 60$) Wide	Exposed ($n = 68$) Narrow	Exposed ($n = 68$) Wide
Invertebrates				
Caterpillars	–	–	6 (15)	1 (7)
Millipedes	4 (21)	1 (25)	15 (45)	3 (9)
Rock spider (*Hemicloea major*)	2 (2)	–	6 (8)	1 (1)
Vertebrates				
Skink (*Cryptoblepharus virgatus*)	–	–	1 (1)	–
Broad-headed snake (*H. bungaroides*)	–	–	1 (1)	–
Velvet gecko (*O. lesueurii*)	6 (8)	3 (3)	19 (36)	9 (9)

[a] Data from the three study sites have been pooled. Table shows number of different pavers under which each species was found, while number in parentheses show the number of different individuals of each species using that paver type. Note that some pavers were used by more than one velvet gecko. Although most geckos used a single paver during the study, six geckos used two different pavers (see text for details).

3.3. *What factors influence paver usage by invertebrates?*

The only invertebrates found under pavers were flat rock spiders, caterpillars, and millipedes (see Table 2). Overall, these invertebrates showed strong preferences for exposed pavers with small crevices (Table 2). Thus, a two-factor ANOVA (with shading and crevice size as factors) showed that paver usage by invertebrates was strongly affected by shading ($F_{1,8} = 19.53, p = 0.002$) and crevice size ($F_{1,8} = 22.78, p = 0.001$), and by the interaction between these two factors ($F_{1,8} = 9.03$, $p = 0.02$). Most invertebrates used exposed pavers with small crevices (Table 2). Although millipedes used more exposed pavers than shaded pavers (Table 2), aggregations of millipedes were often found under shaded pavers (Table 2). Thus, when we used a two-factor ANOVA to compare the numbers of millipedes under each type of paver (with shading and crevice width as the two factors), we found no effects of shading ($F_{1,8} = 0.04, p = 0.84$) or crevice width ($F_{1,8} = 0.70$, $p = 0.43$), and no interaction between the two factors ($F_{1,8} = 1.09, p = 0.33$). Overall, aggregations of millipedes under five shaded pavers (Table 2) resulted in similar numbers of millipedes under shaded (mean = 7.6) and exposed pavers (mean = 9).

3.4. *What factors influence paver usage by geckos?*

We recorded a total of 51 individual *O. lesueurii* under 37 concrete pavers (Table 2). A high proportion (42 of 51 = 82.4%) of geckos were juveniles (< 32 mm SVL) which were < 2 months old when first captured (Webb unpubl. data). Velvet geckos used pavers frequently at site 1 (20 individuals, 16 different pavers) and site 4 (29 geckos, 20 pavers), but rarely at site 2 (two geckos, one paver). We compared the number of different pavers used by velvet geckos among the two treatment types (shading, crevice size) using a two-factor ANOVA (pooled data for sites 1 and 4). This analysis revealed that geckos used exposed rather than shaded pavers ($F_{1,4} = 18.0, p = 0.01$) and small rather than large crevices ($F_{1,4} = 8.0, p < 0.05$). There was no significant interaction between shading and crevice size ($F_{1,4} = 2.0, p = 0.23$); that is, most pavers selected by geckos had small crevices, regardless of the degree of shading. However, the size of the gecko also influenced its choice of paver: larger geckos selected pavers with wider crevices (one-factor ANOVA $F_{1,49} = 8.33$, $p = 0.006$). Some pavers were clearly more attractive to velvet geckos than others. We found four groups of juvenile geckos (two groups of four animals, two pairs) under the same paver (all with narrow crevices) during April. Overall eleven pavers with narrow crevices (nine exposed, two shaded) were used by more than one gecko during the experiment (mean = 2.9, range 2–5 geckos).

Did juvenile geckos display site-fidelity for pavers? At site 1, three juveniles were recorded under the same group of four pavers 35–144 days after their initial capture (mean duration = 100 days), and three animals were recorded under the same paver 14–123 days (mean duration = 87 days) after their initial capture. Thus, at site 1, one third (5 of 15) of juveniles spent relatively long periods of time (>35 days) under the same paver or group of four pavers. In contrast, at site 4 only 11.5% (3 of 26) of juveniles showed site fidelity: after 21 days one juvenile was found under the same paver, two were found under the same group of four pavers, and one had moved to an adjacent set of four pavers 5 m away.

4. Discussion

Our results demonstrate that velvet geckos will use small concrete pavers in the field, and actively select these artificial rocks on the basis of their thermal and physical characteristics. Our data agree with the results of laboratory "choice" experiments and field studies that have demonstrated strong preferences for hot rocks with narrow crevices by *O. lesueurii* (Schlesinger and Shine, 1994a,b; Downes and Shine, 1998; Webb and Shine, 1998a,c). Importantly, some velvet geckos remained under concrete pavers for long periods of time, suggesting that pavers offer physical conditions that successfully mimic those under natural rocks. Indeed, thermal profiles of concrete pavers were very similar to those of naturally occurring rocks of similar thickness and degree of shading. Why did most geckos and invertebrates use exposed rather than shaded pavers? For much of the year (excluding summer), exposed pavers provided temperatures within the range (25–35°C) that is optimal for key physiological and behavioural processes (growth, digestion, reproduction, locomotion) of reptiles (e.g. Lillywhite, 1987), whereas shaded pavers did not (Table 1). Thus, thermal microsites under exposed pavers may allow juvenile geckos to maximise short term behaviours (prey capture, social dominance etc.), and ultimately, long term growth and survivorship (Christian and Tracy, 1981; Huey, 1991). Similarly, insect development and population dynamics are strongly influenced by temperature (e.g. Ratte, 1985; Kingsolver, 1989), so it is not surprising that thermal cues are important determinants of habitat selection for some saxicolous invertebrate fauna.

4.1. Recommendations for future habitat restoration projects

Our results suggest that relatively inexpensive concrete pavers can help restore highly degraded sandstone habitats in south-eastern Australia. Can restoration projects succeed in reversing population declines of *H. bungaroides*? Several ecological characteristics of *H. bungaroides*, including its strong site fidelity, use of few rocks, low dispersal, and reliance on *O. lesueurii* for prey (Webb, 1996) suggest that restoration projects will benefit snakes and their prey. However, our data do not show that the addition of artificial shelter-sites increases gecko abundance; we simply demonstrated that velvet geckos will use such habitats. Longer-term studies, in areas where lizard and snake populations have been depleted by anthropogenic disturbance, are needed to assess whether such usage translates into higher population densities of geckos and snakes.

Nonetheless, our results have obvious implications for the feasibility of habitat restoration in this system. Concrete pavers are inexpensive, long-lasting, and unlikely to be attractive to rock-thieves. In the field, broad-headed snakes and velvet geckos use rocks considerably larger in size than the pavers we used (rocks 5–15 cm thick, 25–65 cm wide versus pavers 5 cm thick, 19 cm wide: Schlesinger and Shine, 1994a; Webb, 1996). Thus, future restoration projects should use larger paving stones (30–45 cm wide) to provide retreat-sites for adult *O. lesueurii* and *H. bungaroides*. Because thin exposed rocks are too hot for reptiles to tolerate in summer (Webb and Shine, 1998a,c), future restoration programs should place artificial rocks in both shaded and exposed areas. Alternatively, a mixture of thin (5–15 cm thick) and thick (>30 cm) concrete rocks could be placed on exposed rock outcrops. Very thick rocks provide thermally suitable micro-sites for reptiles during summer (Webb and Shine, 1998a). To ensure that these artificial retreat-sites are suitable for animals of different body sizes, several crevice sizes should be provided.

The dispersion of artificial rocks in the field may also affect their usage by reptiles. Social factors clearly affect rock selection by velvet geckos; juvenile geckos will share retreat-sites, whereas adult males rarely do so (Schlesinger and Shine, 1994b; Downes and Shine, 1998). The same avoidance of conspecifics occurs in *H. bungaroides* also (Webb and Shine, 1997b). Thus, future studies could manipulate spacing and rock size, using replicated sites, to determine how these factors influence densities of lizards and snakes. The extensive vandalism to our sites within a remote national park means that anthropogenic disturbance will have to be factored into future studies. Simple solutions to reduce disturbance to rehabilitated rock outcrops include the erection of educational signs and bolting the artificial rocks to rock outcrops (e.g. with commercially available masonry bolts).

Finally, we believe that placement of artificial rocks in severely degraded rock outcrops will be needed to conserve *H. bungaroides*, especially given the reluctance of government agencies to ban the collection and sale of bush-rock (Mahony, 1997). Bush-rock collection is still legal in New South Wales, and the demand for this relatively cheap product (for landscaping urban gardens, ponds etc.) is not diminishing. Recent field surveys have highlighted the magnitude of the problem; natural rocks are still being collected (in large numbers) from relatively remote areas like Morton National Park (Webb, 1996; Shine et al., 1998). Degraded rock outcrops that still support very low densities of broad-headed snakes and velvet geckos (Shine et al., 1998) would be ideal sites for testing the long-term feasibility of habitat restoration for saxicolous reptiles.

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