Wildlife Research, 1996, **23**, 221–35

Habitat Suitability Index Model for the Eastern Barred Bandicoot, *Perameles gunnii*

Richard P. Reading[A], *Tim W. Clark*[A], *John H. Seebeck*[B] *and Jennie Pearce*[C]

[A]Northern Rockies Conservation Cooperative, PO Box 2705, Jackson, WY 83001, USA, and School of Forestry and Environmental Studies, Yale University, New Haven, CT 06511, USA.
[B]Department of Conservation and Natural Resources, Flora and Fauna Branch, 4/250 Victoria Pde, East Melbourne, Vic. 3002, Australia. To whom all correspondence should be addressed.
[C]Forestry Section, Faculty of Agriculture and Forestry, The University of Melbourne, Parkville, Vic. 3052, Australia.

Abstract

The eastern barred bandicoot, *Perameles gunnii*, is functionally extinct on mainland Australia. Conservation of this unique taxon is dependent on reintroduction, based on a managed captive-breeding programme that provides founder animals. Existing reserves at which reintroduction has occurred are too small to support long-term genetically viable populations. Therefore, reintroductions must be made at a number of sites and the resulting populations managed as a metapopulation. A habitat-suitability model has been developed to assess and compare reintroduction sites. This is the first application of this concept to an Australian species. The model is composed of five variables—size, habitat structure, predation, shape and security—values of which are combined in a simple relationship to produce comparable mathematical statements for proposed reintroduction sites. The model has been applied to existing reserves to test their contribution to the recovery programme.

Introduction

Eastern barred bandicoots, *Perameles gunnii*, are critically endangered in Victoria (Clark and Seebeck 1990; Reading *et al.* 1992). The last known remnant wild population has been reduced to only a few individuals and is believed to be functionally extinct; that is, the population will be unable to persist over the long term because it is too small and most of the factors that drove it to its present size are still operating (Victorian Department of Conservation and Natural Resources, unpublished data). Restoration of the species therefore rests on the ability of conservationists to locate and reintroduce bandicoots into more-secure locations (Seebeck 1990; Backhouse 1994).

At a minimum, re-establishing wild populations requires an effective captive-propagation programme, identification of suitable habitat and successful translocations and/or reintroductions. This process has been initiated. A captive-breeding programme was established in 1988 (Seebeck 1990; Dufty *et al.* 1995) and substantially upgraded in 1991 following a major programme review (see Reading *et al.* 1992). This programme has succeeded in significantly increasing bandicoot numbers in captivity (Myroniuk 1993; Backhouse *et al.* 1994). Two small (one with *c.* 100 and the other with >500 individuals) populations have been established within fenced reserves using animals translocated from the wild and reintroduced from captivity (see Seebeck and Goldstraw 1993; Dufty *et al.* 1995). However, these reserves, at Hamilton Community Parklands and Gellibrand Hill Park (now called Woodlands Historic Park), may not

1035-3712/96/020221$05.00

be large enough to maintain genetically viable populations of bandicoots over the long term (for discussion on what constitutes a 'genetically viable' population, see Franklin 1980; Soulé 1980; Lande and Barrowclough 1987). Additional wild populations are required to 'spread the risk' of losing the species because of catastrophe. The Claire and Scobie McKinnon Nature Reserve at 'Mooramong', a National Trust property near Skipton, Victoria, was selected as the next site for bandicoot reintroduction, and the first animals were released in December 1992 (Humphries and Seebeck 1995).

In this paper we present a Habitat Suitability Index (HSI) model to facilitate more rigorous and objective comparison and selection of reintroduction sites. HSI models are the outcome of Habitat Evaluation Procedures (HEPs) developed by the United States Fish and Wildlife Service to systematically evaluate and compare wildlife habitat (United States Fish and Wildlife Service 1980, 1981). They have been employed in a variety of wildlife management and conservation programmes in the United States (Cole and Smith 1983; Bovee and Zuboy 1988), including endangered species recovery programmes (e.g. Minta and Clark 1989). HEPs are relatively easy to implement and the resultant HSIs relatively easy to comprehend. This is the first Australian application of this concept.

Although some criteria for selecting bandicoot reintroduction sites have been outlined (Anon. 1993; Backhouse 1994; Humphries and Seebeck 1995), these rely on one overall assessment based on broad criteria. An HSI, alternatively, specifies independent analysis of each of several important habitat components, combines logically and systematically the results of these analyses into a single index, and permits a more objective comparison of potential release sites based on that index (Williams 1988).

Because much of the biology and ecology of eastern barred bandicoots remains unknown, the following HSI therefore relies greatly on expert opinions and should be viewed as preliminary, to be updated when additional information about the species becomes available. Nevertheless, even this preliminary HSI permits a more systematic and objective comparison of potential release sites than do current approaches.

Model Development

The HSI consists of five relatively easily assessed variables: three ecological variables, Size (V_1), Habitat Structure (V_2) and Predation (V_3); a purely spatial variable, Shape (V_4); and a variable composed of a variety of more difficult-to-assess biological and management considerations, Security (V_5). Following Houston *et al.* (1986, p. 107), we combined the variables using the geometric mean, 'because the quantities involved are measured on a ratio scale and the variables are not arithmetic sequences but geometric'. We believe that the variables change geometrically rather than arithmetically, but acknowledge that this is based solely on expert opinion. It therefore makes sense to combine them using the geometric mean. The variables are given equal weight, although we recognise that this is an arbitrary decision; we do not have overwhelming reasons to apply any form of unequal weighting to the variables. Therefore, the values of the variables are combined in the following expression:

$$\mathrm{HSI} = (V_1 \times V_2 \times V_3 \times V_4 \times V_5)^{1/5}.$$

Eventually, we would attempt to apply a sensitivity analysis to these variables. Such an analysis would provide an objective assessment of the weighting factor.

Curves were generated to represent the hypothesised relationship between each variable and its relative value to bandicoot conservation. We again followed Houston *et al.* (1986) and, where possible, used a logistic function $y = (1 + \mathrm{k}e^{rt})^{-1}$ to describe the relationship between a variable and its Suitability Index (SI: see below) (y is the dependent variable in question, in this case SI; k is a constant, e the natural logarithm, r the rate of increase of y and t is the independent variable by which y varies). Smooth logistic curves were used where possible because habitat relationships (1) are intrinsically non-linear, (2) change gradually relative to their value to bandicoots and (3) confer relatively little additional value to bandicoots for changes in more-extreme values (Houston *et al.* 1986). Each of the five variables are defined and described in detail below.

Size Index—V_1

An important consideration for any potential site is the number of animals it is capable of supporting. Carrying capacity depends upon both the size of the site and its quality. Size is considered here. Habitat quality is assessed in the remaining four variables.

Obviously, other factors being equal, the larger a potential release site, the greater the number of animals it is capable of supporting and, therefore, the higher it should be ranked relative to smaller sites. However, as large sites become increasingly bigger, they will confer smaller and smaller benefits to the conservation of the species, especially for sites large enough to support genetically and demographically viable populations over large time scales (i.e. hundreds of years). However, relatively small changes in the size of very small sites probably confer substantial additional benefit to conservation, because any increase in the amount of habitat for smaller reserve increases the probability of population persistence.

Conservation geneticists have suggested that long-term genetic conservation (i.e. hundreds of generations) of a species requires a genetically effective population of 500 individuals in a panmictic population with an equal sex ratio, no overlapping generations, a stable age distribution and a random distribution of reproductive success (Franklin 1980; Lande and Barrowclough 1987). Because this ideal situation does not exist in nature, several thousand individuals are needed. Short-term conservation (i.e. *c.* 10 generations) requires a genetically effective population of about 50 individuals (Franklin 1980; Soulé 1980), which translates to several hundred individuals in reality. However, populations never fulfil all of these criteria. To address this problem, geneticists developed a set of equations to permit determination of the effective population size (N_e) of a population given its actual (or censused) population size (N), its demographics and information about the species' ecology (Crow and Kimura 1970, 1972; Lande and Barrowclough 1987). Once N_e is calculated, the N/N_e ratio is easily determined. Multiplying N/N_e by 500 or 50 then gives the actual population size required for long-term or short-term species conservation, respectively.

Three studies determined N_e for eastern barred bandicoots. Myroniuk (1993) determined N_e for the captive population of bandicoots and found $N/N_e = 5{\cdot}65$. His calculations, while the most accurate of the three studies, may not be directly comparable to wild populations.

Two studies calculated N_e for the last known wild Victorian population of bandicoots. First, for a census population of 633 bandicoots, Sherwin and Brown (1990) estimated $N_e = 67$ ($N/N_e = 9{\cdot}45$), but assumed a stable population. Second, Robinson *et al.* (1990) used additional data on decline of bandicoot populations to obtain better estimates of mean reproductive output. They performed two calculations of N_e, one 'pessimistic' and the other 'optimistic.' The former used more-conservative estimates of N, sex ratio and variance in lifetime reproductive output. Their results yielded $N/N_e = 7{\cdot}37$ (pessimistic or conservative) and $N/N_e = 2{\cdot}45$ (optimistic). Because Robinson *et al.* (1990) incorporated data on a greater number of demographic variables, their estimates are probably the most reliable and suggest that $N/N_e = 2{\cdot}45$–$7{\cdot}37$ (median = 4·91). For $N_e = 500$, this translates to a population of 1225–3685 (median = 2455) bandicoots ($N_e \times N/N_e = N$) necessary for long-term conservation of the species. For $N_e = 50$ this translates to 123–369 (median = 246) bandicoots for short-term conservation, well below the estimated 650 or more bandicoots surviving in current (July 1995) captive and wild populations (Myroniuk 1993; Seebeck and Bowley 1993; Seebeck and Goldstraw 1993; Backhouse 1994; Victorian Department of Conservation and Natural Resources, unpublished data). This analysis will therefore focus on habitat requirements for long-term conservation.

The area required for maintaining 1225–3685 bandicoots depends greatly on habitat quality. Studies of wild populations of eastern barred bandicoots yielded greatly varying densities. Indeed, Minta *et al.* (1990, pp. 64, 65) caution against inappropriate use of estimates of bandicoot density because 'the complex and extreme heterogeneity of the eastern barred bandicoots' environment' in Hamilton leads to 'a severe lack of [density] uniformity'.

Reported densities of bandicoots include naive density estimates of 0·85 ha^{-1} (Heinsohn 1966), 0·44 ha^{-1} (Brown 1985), 1·49–5·25 ha^{-1} (Dufty 1988) and 0·59–4·79 ha^{-1} (Dufty 1991*a*, 1991*b*). Using the more rigorous mark–recapture programme CAPTURE to analyse population densities, Minta *et al.* (1990, p. 66) estimated that 'densities may be in the neighbourhood of 1·5 eastern barred bandicoots per ha'.

Estimates of bandicoot density therefore vary from 0·44 to 4·79 ha^{-1}, with the most rigorous estimate about 1·5 ha^{-1}. We relied on the latter estimate. For populations of 1225–3685 bandicoots (i.e. for long-term conservation; see above), a density of 1·5 animals ha^{-1} translates to 1837·5–5527·5 ha (median = 3682·5 ha). For populations of 123–369 bandicoots (i.e. for short-term conservation; see above), densities of 0·44–4·79 animals ha^{-1} translate into 54·1–239·5 ha (median = 146·8 ha) and a density of 1·5 animals ha^{-1} translates to 184·5–553·5 ha (median = 369 ha).

Size index

On the basis of these data, we decided that a site of a site of 50 ha would receive a Size SI rating of 0·10, a site of 1000 ha would receive a rating of 0·90, and a site of 2000 ha would receive a rating of 0·99. We fitted a curve to these values to create an initial relationship for the Size index, using the equation

$$V_1 = f(x) = 1 - 1{\cdot}01e^{-0{\cdot}0023x},$$

in which x is the size of the site in hectares (Fig. 1).

In developing this equation we recognised the difficulty of locating sites larger than 1000 ha, even though such sites would be desirable from a genetic and demographic management standpoint. There are no sites presently known to us in western Victoria that exceed that size. Suitable habitat on the western plains is extremely fragmented and realistically there is little chance of consolidating conservation-oriented property to reach that level. The difficulty of locating potential reintroduction sites sufficiently large to maintain a genetically viable population of bandicoots in the long term will necessitate managing several smaller populations as a single 'metapopulation' with artificial migration between subpopulations (see Gilpin 1991; Hanski and Gilpin 1991).

Habitat Structure Index—V_2

Habitat structure, including both living and dead vegetation and artificial shelters (e.g. brush piles, rubbish piles, human-made structures), is an important component of bandicoot habitat that provides cover (see below) and possibly increases prey availability. Several authors have suggested the importance of habitat structure to bandicoots. Dufty (1991*a*, p. 113) found that 'bandicoots appeared to select habitat principally on its structural characteristics although floristic diversity was also important. It appears that habitat structure is the primary determinant of habitat selection by *Perameles gunnii*'. Similarly, Minta *et al.* (1990, p. 57) found that trapping success was associated with sources of habitat structure and stressed the 'importance of structural (cover) components of the habitat'. Heinsohn (1966) found that Tasmanian eastern barred bandicoots appeared to prefer habitat mosaics of open pastures mixed with areas of cover. Unfortunately, the degree of importance and type and amount of cover necessary for bandicoot survival have not been quantified (see Driessen and Hocking 1991).

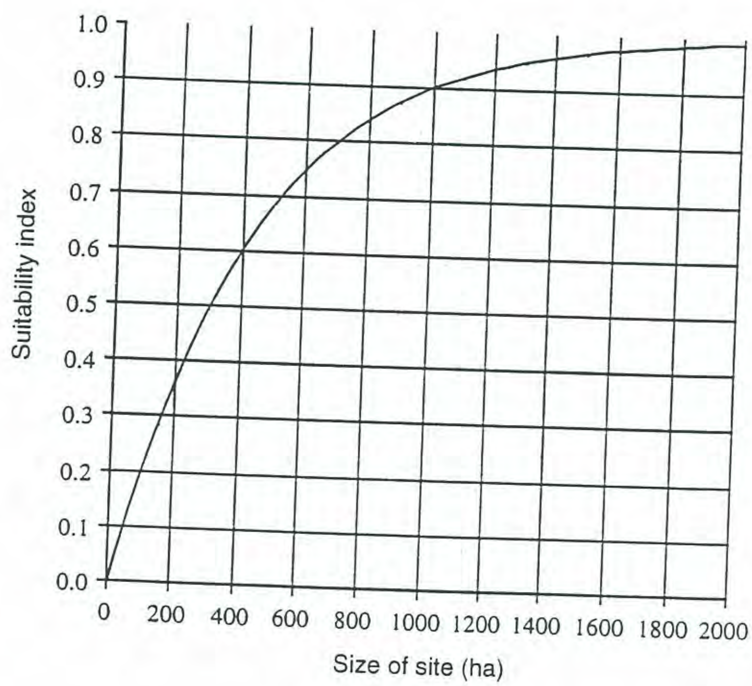

Fig. 1. V_1: Size Suitability Index. $V_1 = 1 - 1{\cdot}01e^{-0{\cdot}0023x}$, where x is the size of the site in hectares.

Preliminary analyses of the importance of habitat structure to bandicoots examined correlations between various habitat parameters (e.g. grass, shrub and tree height, slope, percentage of bare ground and vegetative cover) at trap sites and trapping success rates (Pearce 1994; Dufty *et al.* 1995). While these analyses found certain parameters significantly correlated with trapping success, the specific variables varied from season to season and year to year, severely limiting their predictive power (Pearce 1994). Indeed, when we used significant parameters from one trapping session to develop logistic models to predict future trapping success, they worked no better than random. This may have been due to the *post hoc* nature of the original habitat analyses. However, this result emphasises the importance of testing correlations derived from inductive analyses on additional data prior to using the results for management decisions. Additional studies are clearly warranted.

Despite our inability to adequately define habitat structure using current data, we believe that habitat structure, or cover, is important for bandicoots. Pearce (1994) found that sites where bandicoots were trapped were associated with high levels of shrub cover; other 'cover' variables at such sites included tree cover, good grass cover and structural complexity. We therefore included a Habitat Structure SI (V_2) as a part of our HSI. However, we also know that bandicoots move into areas that contain no cover, such as grazed pastures, to forage (Seebeck 1979; Dufty 1991*a*). Therefore, V_2 should include both the percentage of cover (CV) and the distribution of that cover (DC). We assumed that sites without cover will not support bandicoots, but that a relatively small percentage of cover will support some animals. We further assumed that, as the percentage of cover within a site increases, the suitability of that site for bandicoots increases rapidly, and that, as the cover reaches about 40–50%, the site should be considered excellent habitat. Cover, for the purposes of these analyses, was defined as areas dominated by artificial shelter (e.g. brush and rubbish piles), shrubs, and tall (>0·35 m) grass that is not subject to grazing by domestic livestock, frequent (>half-yearly) fires or heavy grazing by native or feral wildlife. Using this definition, sites without cover would be considered unsuitable for bandicoots (i.e. SI = 0), sites with 2% cover would receive a SI of 0·1, sites with 20% cover would receive a SI of 0·66, and sites with 100% cover would be ideal for bandicoots (i.e. SI = 1·0; Fig. 2). We used these relationships to develop an initial Percentage of Cover SI (*CV*) by fitting a curve to these values. Thus, we defined *CV* as follows:

$$CV = f(y) = 1 - 1{\cdot}01e^{-5{\cdot}5y}$$

where y is the percentage of cover (Fig. 2).

We further assumed that the distribution of habitat cover is important to eastern barred bandicoots. Although areas without cover are utilised by bandicoots for feeding, we hypothesise that the value of the habitat to bandicoots declines with distance from protective cover. Dufty (1991*a*) noted that bandicoots foraged up to 30 m from cover. We believe they rarely forage greater than 50 m from cover. We therefore assumed that sites with a smaller percentage of land more than 50 m from cover are better for bandicoots, and that, as the percentage of land more than 50 m from cover increases, the suitability of the site for bandicoots decreases. Thus, we define the Distribution of Cover SI (*DC*) as follows:

$$DC = f(z) = 1 - [1 + 250e^{-11z}]^{-1}$$

where z is the percentage of land more than 50 m from cover (see definition of cover above) (Fig. 3). By this definition, sites without any land more than 50 m from cover would be ideal and receive a SI of 1·0, sites with 50% of the land more than 50 m from cover would receive a SI of 0·5 and sites with more than 70% of the land more than 50 m from cover would receive SIs of less than 0·1 (Fig. 3).

Habitat Structure SI

Since we believe that both the presence of cover and its distribution are equally important to bandicoots, we combined them into a single index as follows:

$$V_2 = (CV \times DC)^{1/2}.$$

Predator Index—V_3

Predation by introduced carnivores, especially red fox, *Vulpes vulpes*, and cats, *Felis catus*, is one of the most important factors implicated in the decline of wild bandicoots (Brown 1989; Seebeck *et al.* 1990). Predation may also reduce the chances for successful reintroduction, especially in the absence of predator control. The first releases of eastern barred bandicoots into the Nature Reserve at Gellibrand Hill Park

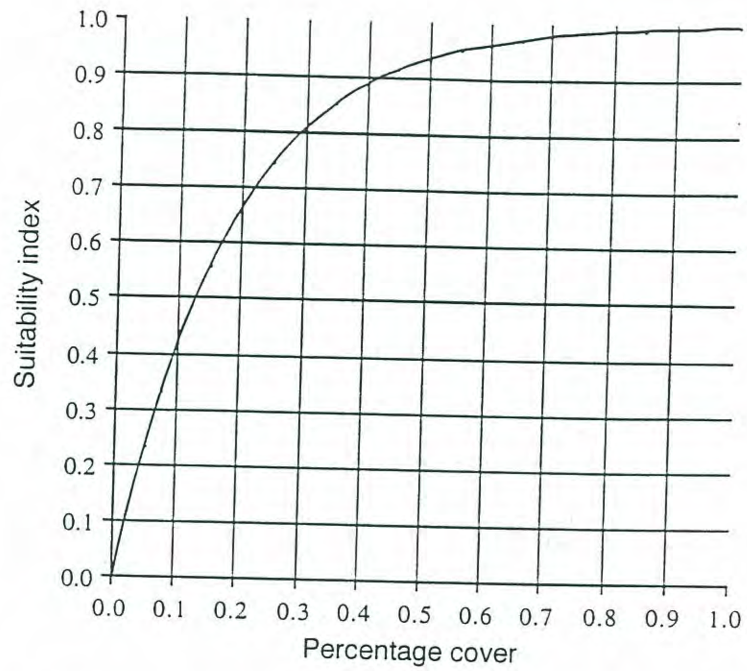

Fig. 2. *CV*: Percentage Cover Suitability Index. $CV = 1 - 1{\cdot}01e^{-5{\cdot}5y}$, where y is the percentage of cover (see text for definition of cover).

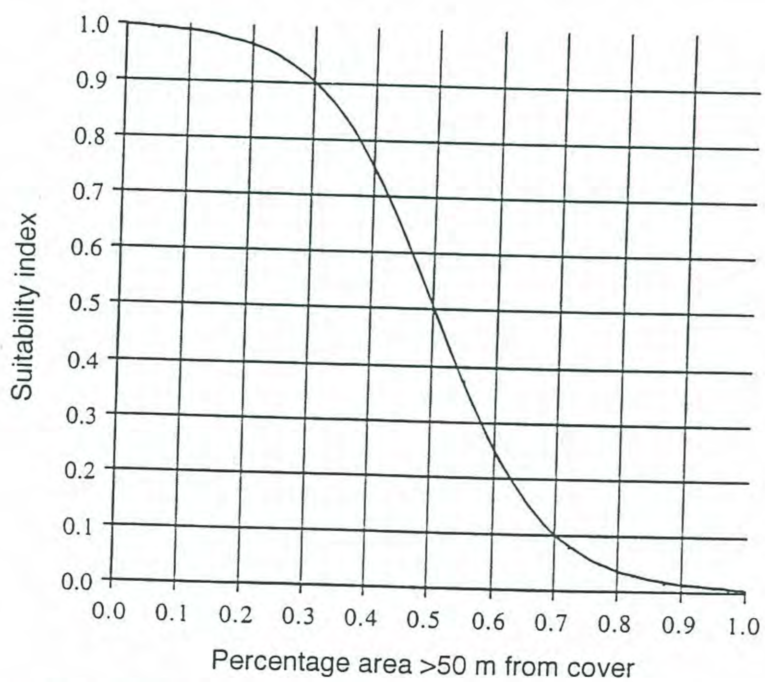

Fig. 3. *DC*: Distribution of Cover Suitability Index. $DC = 1 - (1 + 250e^{-11z})^{-1}$, where z is the percentage of land more than 50 m from cover (see text for definition of cover).

suffered a known 40% mortality due to predation (Dufty *et al.* 1995) and one release of bandicoots into Mooramong experienced heavy mortality due to fox predation, when four of five animals released were killed (Victorian Department of Conservation and Natural Resources, unpublished data). All sites that currently possess reintroduced populations of bandicoots maintain continuing, intensive predator-control programmes as an integral part of site management. Potential for disease transmission, especially by cats, represents a second source of mortality directly attributable to predators. Toxoplasmosis (*Toxoplasma gondii*) has already been implicated in the decline of the wild population of bandicoots in Hamilton (Lenghaus *et al.* 1990; Seebeck *et al.* 1990).

Unfortunately, monitoring predator abundance is difficult and expensive. Therefore, the predator index (V_3) is based on two parameters: *PC*, the potential for controlling predator numbers, and *DT*, distance to nearest town.

The first component (*PC*) is assessed by expert opinion on a scale of 1–5, where 1 represents a site with the poorest potential for predator control and 5 represents a site with the greatest potential. Because cats are the major vectors for toxoplasmosis, one component of the index (*DT*) is simply a measure of the distance of the site from the nearest town. Since cats also prey upon bandicoots, this index is also a measure of potential predation pressure. We have assumed that cat densities decline with distance from a town, and so, the further the proposed reintroduction site is from a town, the higher the score. The following ratings are thus given for each distance category: <1 km, *DT* = 1; 1–2 km, *DT* = 2; 2–5 km, *DT* = 3; 5–10 km, *DT* = 4; and >10 km, *DT* = 5.

Predator index

Because adequate predator control reduces the danger of being near sources of cats, *PC* is given twice the weight of *DT*. Cats attempting to enter the release site have a good chance of being controlled (i.e. killed) if a control programme is in place. We consider that a good control programme is more important than a site being far from a town. Therefore, the two components of the predator index are combined in the following expression:

$$V_3 = (2 \times [PC/5] + [DT/5])/3.$$

Shape Index—V_4

The shape of a potential reintroduction site is often an important consideration, especially for sites surrounded by hostile environments. This so-called 'edge-effect' may be particularly important for bandicoots if they are subject to greater predation [because of increased exposure to predators: see Yahner (1988) for a discussion of this issue], pesticide poisoning [in relation to agricultural use; Lenghaus *et al.* (1990) have reported the effects of such poisons on bandicoots], or other adverse factors outside the proposed release site.

Reserve design theory has become an important field of study within conservation biology. Current theory recognises the importance of minimising the amount of edge relative to area. Therefore, in general, reserves and reintroduction sites should be as round as possible. We followed Minta and Clark (1989) and measured the 'roundness' of potential reintroduction sites using the following two indices: *AR*, the Axis Ratio index, and *SS*, the Site Shape index or area/perimeter ratio.

The *AR* measures how long or how compact a site is. The more linear a site, the less desirable. The *AR* is measured by dividing the minor axis (greatest width) of a site by its major axis (greatest length). Axis ratios therefore vary from zero to one, with better sites having ratios closer to one. For example, circles and squares have identical widths and lengths; their axis ratios are therefore unity. The *AR* is easy to calculate and adds to the definition of roundness of a given area.

The *SS* index compares the area-to-perimeter ratio of a site to a circle of the same area. The inverse is taken to standardise the value on a scale of zero to one. As such, it represents a more direct measure of the relative amount of edge for each potential reintroduction site, according to the following equation:

$$SS = (SA \times \pi)^{1/2}/SP$$

where *SA* is Site Area and *SP* is Site Perimeter.

The *AR* and *SS* are obviously related. As Minta and Clark (1989, p. 38) stated, 'There is always potential compensation among variables that are related (co-linear) to some degree as in any habitat and/or suitability model. Therefore, compensation is not only an essential process but is part of the rationale in combining variables in a model. Likewise, any variable or parameter in a statistical or mathematical relationship (e.g.

the mean and variance of a distribution) can be taken in isolation and shown to be woefully inadequate by itself, especially when extreme examples are used'. Two areas may have the same SS but different AR (e.g. an oblong area with smooth edges compared with a roundish area with wavy boundaries; the resultant Shape indices are different).

Shape index

The two measures are combined into a single Shape index in the following expression:

$$V_4 = (AR \times SS)^{1/2}.$$

Security Index—V_5

A variety of additional variables are also important to the assessment of potential bandicoot-reintroduction sites. Most of these variables are not easily measured and therefore rely heavily on expert opinion. To reduce individual bias, these variables should be assessed by a number of different, qualified personnel and combined into a single index value from mean scores.

Five different variables, some composed of more than one parameter, are included in the Security index: fire potential, land tenure, the degree of local support or opposition, on-site support (resources), and availability to bandicoot reintroduction. Each variable or parameter is rated on a scale of 1–5, with 1 representing the poorest rating and 5 the best (see Appendix).

The first variable, fire, dramatically reduces the cover immediately available to bandicoots and may kill animals or their prey. The effects of fire on bandicoots and their cover and prey will depend on fire intensity; there is some indication that bandicoots forage on recently burned ground and may survive low-intensity fires while remaining in their nests (G. Bowley, personal communication, 1993). Periodic, low-intensity fires may indeed be a requirement in the medium- to long-term management of reserves for bandicoots. However, we included a Fire Potential index (FP) to measure the potential for catastrophic, uncontrolled fire that would burn all or most of the reserve and kill all or most bandicoots. This index is rated on a scale of 1–5, where 1 indicates that the site is most likely to experience such a fire, 5 the least likely.

The second variable included in the Security index is a Land Tenure index (LT). Because publicly owned land is more secure and potentially more easily managed for bandicoots, the following ratings are given for each land tenure category: public land = 0%, $LT = 1$; 1–25%, $LT = 2$; 26–50%, $LT = 3$; 51–75%, $LT = 4$; >75%, $LT = 5$.

The level of local support or antagonism toward a proposed reintroduction comprises the third variable in the security index, a Local Support index (LS). Local support is crucial to any reintroduction programme. Inadequately addressing local values, attitudes, knowledge and opinions prior to initiating a reintroduction has resulted in tragic failures in past programmes (see Hook and Robinson 1982; Belden *et al.* 1990). Preferably, knowledge and value aspects should be investigated by means of rigorous social-science techniques early in the assessment of potential reintroduction sites (Reading and Kellert 1993). Reading *et al.* (1994) examined the values and attitudes of residents at Hamilton to the bandicoot and its conservation, finding over 90% in favour of bandicoot conservation; however, they identified some areas of concern, confirming the need for such studies to be conducted. If the studies are not conducted, then knowledgeable participants, including locals, should be asked to rate the degree of local support or antagonism on a simple 1–5 scale.

The fourth component of the Security index measures the amount of on-site support. This On-site Support index (OS) comprises two variables: personnel (P) and money and equipment (E). The better staffed a site, in terms of available managers and biologists, and the more resources it has available to contribute to bandicoot conservation, the better the chances for reintroduction success. These variables are therefore assessed subjectively on a 1–5 scale and combined in the following expression:

$$OS = (P + E)/2.$$

The fifth and final component of the Security index is an index of site availability. The Availability Index (AV) is simply a subjective assessment of whether bandicoot reintroduction would be permitted to occur on the proposed site. Sites that are solely public land would presumably be the most secure; however, long-term commitments from covenants or participation in programmes like Victoria's 'Land for Wildlife' would increase the security of private landholdings. The rating is again made on a scale of 1–5.

Security index

The overall Security index is determined from the arithmetic mean of the seven afore-mentioned indices (see Appendix). They are therefore combined in the following equation:

$$V_5 = ([FP/5] + [LT/5] + [LS/5] + \{[(P + E)/2]/5\} + [AV/5])/5$$
$$= ([FP/5] + [LT/5] + [LS/5] + [OS/5] + [AV/5])/5.$$

Habitat Suitability Index

The values of all variables included in the HSI are combined in the following expression:

$$\mathrm{HSI} = \{[V_1] \times [(\mathrm{CV} \times \mathrm{DC})^{1/2}] \times [(2 \times [\mathrm{PC}/5] + [\mathrm{DT}/5])/3] \times [(\mathrm{AR} \times \mathrm{SS})^{1/2}] \times [([\mathrm{FP}/5] + [\mathrm{LT}/5] + [\mathrm{LS}/5] + \{[(\mathrm{P} + \mathrm{E})/2]/5\} + [\mathrm{AV}/5])/5]\}^{1/5}$$
$$= (V_1 \times V_2 \times V_3 \times V_4 \times V_5)^{1/5}.$$

Issues not Addressed

We did not include assessments for either food or water in this model, principally because we do not consider those factors to be limiting in relation to the other variables assessed. Eastern barred bandicoots feed primarily on soil invertebrates, but also consume some plant material. Major foods appear to be earthworms (Annelida: Oligochaeta), Coleoptera (beetle) larvae and Orthoptera (grasshopper and cricket) adults; bandicoots also eat Lepidoptera (moth and butterfly) larvae, when available, Diptera (fly, gnat and mosquito) larvae, Hymenoptera (bee and ant) larvae, small amphibians, fruit, bulbs of onion grass (*Romulea rosea*), and other plant material (Heinsohn 1966; Brown 1989; Dufty 1988, 1991*a*, 1991*b*). The abundance and availability of these food items varies seasonally. The most-preferred foods appear to be earthworms, Coleoptera larvae, Orthoptera adults and Lepidoptera larvae, while less-preferred foods include Diptera larvae, Hymenoptera larvae, fruit and onion grass bulbs.

The relationship between food and habitat preference is relatively unknown. Most diet studies have examined food items consumed by bandicoots, but few have attempted to correlate food abundance with population size or density of bandicoots. Dufty *et al.* (1995) found no significant correlation between bandicoot captures and invertebrate abundance in a semi-wild population, and R. Gibson (University of Ballarat, unpublished data) found that invertebrate abundance did not differ significantly between bandicoot habitat of native compared with exotic vegetation. As a result, we assume that food is not a limiting resource for most bandicoot populations and hence do not include food as a separate index. Nevertheless, knowledge of the diet of eastern barred bandicoots could potentially permit comparison of sites with respect to the abundance and mass of different foods. Future studies should assess the minimum dietary requirements of bandicoots (i.e. energetic studies) and the effect of prey abundance on habitat preferences and densities of bandicoots.

Soil invertebrates, and therefore bandicoots, may be associated with certain soil and vegetative characteristics. For example, Dufty (1991*a*, 1991*b*) found that foraging holes of bandicoots were positively correlated with ground cover and plant height and negatively correlated with soil compaction, soil pH and native grasses. As such, the Habitat Structure index (V_2) may include a partial index of food availability. More research is clearly needed.

Although the HSI does not include a Food index, one may be found subsequently to be necessary and, if so, could be obtained by sampling the variety and abundance of invertebrate fauna and vegetative food items at potential release sites. To facilitate comparison, the mass of food items (in grams) should be measured so as to reflect the relative abundance of food groups available. However, if prey items of bandicoots are found associated with areas characterised by certain soil and vegetative features, invertebrate sampling may be unnecessary, thereby greatly facilitating habitat assessment.

We also did not include a Water Availability index in our HSI. Like food, we do not consider water to be a limiting factor for most bandicoot populations. Murphy (1993) found that captive bandicoots very rarely drank water; in two of three 2-night trials, bandicoots did not drink at all. Dufty (1994) observed only one incident of drinking during 42 h of observation. Some bandicoots trapped for population monitoring have been observed to drink upon release (J. H. Seebeck, personal observation), perhaps related to the low water content of the bait provided. Nevertheless, the availability of standing water may be important to bandicoots under extreme climatic conditions (e.g. extended drought or fire).

Water availability also influences both vegetation types and vegetation growth. This, in turn, will affect the amount and quality of cover and may influence the variety and abundance of prey. However, while moister sites will generally result in greater vegetative growth, this may be incorporated in our Habitat Structure index. Future studies should examine the influence, if any, of water availability on habitat selection by bandicoots.

Model Application

We examined the suitability of the three sites that contained reintroduced populations of eastern barred bandicoots in Victoria—Gellibrand Hill Park (GHP), Hamilton Community Parklands (HCP) and Mooramong Nature Reserve (MNR)—by applying the model to data from each site (Table 1). We applied the model to MNR twice: (1) using data from the current Nature Reserve and (2) using data that includes a portion of the site that will later be included in the Nature Reserve. We included 50 m surrounding the MNR because the National Trust property at Mooramong is far larger than the Nature Reserve, bandicoots are not constrained to the Nature Reserve, and bandicoots are known to forage in grazed pastures near cover (Dufty 1991*a*; Victorian Department of Conservation and Natural Resources, unpublished data).

We applied data from each site to the model to derive SIs for each of the five variables and an overall HSI (Table 2). GHP received the highest HSI, with a score of 0·77. HCP and MNR received identical HSI scores of 0·63; however, with planned future additions to MNR included in the analyses, the score rose to 0·68. This increased HSI was primarily a result of the 0·32–0·42 increase in the Size index (V_1). However, because the proposed additions to MNR would result in a better perimeter-to-area ratio (*SS*), the Shape index (V_4) also increased. The relatively high HSI of GHP was a result of its larger size (V_1) and better Security index (V_5) compared with the other sites. All three sites received excellent Habitat Structure indices (V_2) of 0·99. HCP's relatively low score resulted from its small size (only 100 ha), while MNR, as it currently exists, received a relatively low HSI primarily because of its modest size (171 ha) and long, narrow shape (V_4) (Tables 1 and 2).

The HSI scores reflect the probable contribution of each site to bandicoot conservation and recovery. Recent monitoring at GHP and HCP yielded population estimates of 500 and 85 animals, respectively (Seebeck and Bowley 1993; Seebeck and Goldstraw 1993), although at HCP the population crashed during 1994 (Seebeck and Goldstraw 1995); unforseen habitat alteration and increased predation, coupled with a period of below-average rainfall, were probable causes. At least 45 animals currently inhabit MNR (Humphries and Seebeck 1995); however, the reintroduction is still in its initial stages. Numbers will hopefully increase as

Table 1. Summary data for Gellibrand Hill Park (GHP), Hamilton Community Parklands (HCP) and Mooramong Nature Reserve (MNR), three sites containing reintroduced populations of eastern barred bandicoots in Victoria

Variable	GHP	HCP	MNR[A]	MNR[AB]
Area (ha)	400	100	171	237·5
Area with cover (%)	80	92	69	77
Area >50 m from cover (%)	8	7	8	6
Perimeter (km)	12·6	5·3	7·6	7·7
Axes (km)				
Length	3·5	1·48	2·6	2·6
Width	2·45	1·48	1·2	1·2
Distance to town (km)	0	0	7	7
Public land (%)	100	100	0	0

[A]Includes fenced Nature Reserve and 50 m from fence boundary.
[B]Includes future additions to the Nature Reserve.

Table 2. Component index and Habitat Suitability Index (HSI) values for Gellibrand Hill Park (GHP), Hamilton Community Parklands (HCP) and Mooramong Nature Reserve (MNR), three sites containing reintroduced populations of eastern barred bandicoots in Victoria

See text for further explanation of the variables

Index	GHP	HCP	MNR[A]	MNR[AB]
V_1: Size	0·60	0·20	0·32	0·42
Percentage Cover (*CV*)	0·99	0·99	0·98	0·99
Distribution of Cover (*DC*)	0·99	0·99	0·99	0·99
V_2: Habitat Structure	0·99	0·99	0·99	0·99
Predator Control (*PC*)	5·0	5·0	4·0	4·0
Town Distance (*DT*)	1·0	1·0	4·0	4·0
V_3: Predator	0·73	0·73	0·80	0·80
Site Shape (*SS*)	0·56	0·67	0·61	0·72
Axis Ratio (*AR*)	0·70	0·84	0·46	0·46
V_4: Shape	0·63	0·75	0·53	0·58
Fire Potential (*FP*)	5·0	4·5	4·0	4·0
Land Tenure (*LT*)	5·0	5·0	1·0	1·0
Local Support (*LS*)	5·0	4·5	5·0	5·0
On-site Personnel (*P*)	5·0	3·5	4·0	4·0
On-site Equipment (*E*)	5·0	4·0	4·5	4·5
On-site Support (*OS*)	5·0	3·75	4·25	4·25
Availability (*AV*)	5·0	5·0	5·0	5·0
V_5: Security	1·0	0·91	0·77	0·77
HSI	0·77	0·63	0·63	0·68

[A]Includes fenced Nature Reserve and 50 m from fence boundary.
[B]Includes future additions to Nature Reserve.

bandicoots become established and are released into different parts of the Nature Reserve. Still, given known densities of bandicoots (Heinsohn 1966; Brown 1985; Minta *et al.* 1990; Dufty 1991*b*), it is doubtful MNR would ever be able to support the number of bandicoots currently found at GHP, even after the proposed additional area is included.

Discussion

The HSI presented above represents a first attempt at modelling preferred habitat of the eastern barred bandicoot. Unfortunately, because so little is known about the biology and ecology of bandicoots, much of the model's development relied on subjective analyses and expert opinion. More rigorous research on the biology and ecology of bandicoots is urgently needed to increase our knowledge of the species and the habitat it requires.

Nevertheless, this HSI provides managers and conservationists with a more objective, rational approach to selecting future bandicoot reintroduction sites than is currently available. However, we again stress the importance of continual change and update to the HSI as new data and hypotheses about bandicoot habitat use emerge. As Schamberger *et al.* (1982) stated, HSI 'models should be viewed as hypotheses of species–habitat relationships rather than statements of proven cause and effect relationships'.

In addition, for more accurate comparisons, analyses of different sites should be performed during the same season, and preferably during the same year. The relative importance of areas with a high degree and a low degree of habitat structure to habitat selection by, and survival of, eastern barred bandicoots requires further analysis, preferably with radio-telemetry techniques. Sites should also be assessed at different times during the year to examine whether their rating changes seasonally relative to other sites. Finally, studies should examine the influence of climatic change, especially of rainfall, on the Habitat Structure Index (V_2) and food abundance.

We recommend immediate implementation of the model. The model should be applied to current bandicoot habitats, identified reintroduction sites, and the widest possible array of other potential sites.

The HSI process is a highly generalised approach to assessing habitat. It enables systematic, objective comparisons and assessments betweeen sites and can thus be applied, given appropriate specific biological knowledge, to any species.

Acknowledgments

Support for the first two authors was provided by the Northern Rockies Conservation Cooperative and the Victorian Department of Conservation and Natural Resources. Special support was given by Pam and Ted Thomas of 'Aspen', Hamilton, Victoria. Additional assistance and critical comment were provided by G. Backhouse, R. Begg, G. Bowley, P. Goldstraw and R. Humphries of the Victorian Department of Conservation and Natural Resources; M. Driessen and G. Hocking of the Tasmanian Department of Parks, Wildlife and Heritage, R. Gibson of Ballarat University; and J. Gibbs of Yale University.

References

Anon. (1993). Release site assessment. Draft criteria for selection of private land sites for release of eastern barred bandicoots. Eastern Barred Bandicoot Recovery Program. Newsletter No. 2. Department of Conservation and Natural Resources and Zoological Board of Victoria, Melbourne.

Backhouse, G. N. (1994). Recovery plan for the eastern barred bandicoot *Perameles gunnii*. 1994–1997. Department of Conservation and Natural Resources, Flora and Fauna Branch, Melbourne.

Backhouse, G. N., Clark, T. W., and Reading, R. P. (1994). The Australian Eastern Barred Bandicoot Recovery Program: evaluation and reorganisation. In 'Saving Endangered Species: Professional and Organisational Lessons for Improvement'. (Eds T. W. Clark, R. P. Reading and A. L. Clarke.) pp. 251–71. (Island Press: Washington, DC.)

Belden, R. C., Hagedorn, B. W., and Frankenberger, W. B. (1990). Panther captive breeding/reintroduction feasibility. Final Performance Report, Study No. 7507, Florida Panther Research, 1 July 1985–30 July 1990. Florida Game & Fresh Water Fish Commission, Tallahassee.

Bovee, K. D., and Zuboy, J. R. (Eds) (1988). Proceedings of a workshop on the development and evaluation of habitat suitability criteria. *US Fish & Wildlife Service Biological Report* **88**(11), 1–407.

Brown, P. R. (1985). A preliminary report on investigations into the ecology and conservation of the mainland population of the eastern barred bandicoot *Perameles gunnii*: March 1983–June 1985. World Wildlife Fund Australia Report—Project 55.

Brown, P. R. (1989). Management plan for the conservation of the eastern barred bandicoot, *Perameles gunnii*, in Victoria. Arthur Rylah Institute for Environmental Research Technical Report Series, No. 63. Department of Conservation, Forests and Lands, Melbourne.

Clark, T. W., and Seebeck, J. H. (Eds) (1990). 'Management and Conservation of Small Populations.' (Chicago Zoological Society: Brookfield, Illinois.)

Cole, C. A., and Smith, R. L. (1983). Habitat suitability indices for monitoring wildlife populations—an evaluation. *Transactions of the North American Wildlife & Natural Resources Conference* **48**, 367–75.

Crow, J. F., and Kimura, M. (1970). 'An Introduction to Population Genetics Theory.' (Harper and Row: New York.)

Crow, J. F., and Kimura, M. (1972). The effective number of a population with overlapping generations: a correction and further discussion. *American Journal of Human Genetics* **24**, 1–10.

Driessen, M. M., and Hocking, G. J. (1991). The Eastern Barred Bandicoot Recovery Plan for Tasmania: research phase. Tasmanian Department of Parks, Wildlife & Heritage, Hobart.

Dufty, A. C. (1988). The distribution, population abundance, status, movements and activities of the eastern barred bandicoot, *Perameles gunnii*, at Hamilton. B.Sc. Honours Thesis, La Trobe University, Melbourne.

Dufty, A. C. (1991*a*). Conservation biology and management of the eastern barred bandicoot, *Perameles gunnii*, in Victoria. M.Sc. Thesis, University of Melbourne.

Dufty, A. C. (1991*b*). Some population characteristics of *Perameles gunnii* in Victoria. *Wildlife Research* **18**, 355–66.

Dufty, A. C. (1994). Field observations of the behaviour of free-ranging eastern barred bandicoots, *Perameles gunnii*, at Hamilton, Victoria. *Victorian Naturalist* **111**, 54–9.

Dufty, A. C., Seebeck, J. H., McKay, J., and Watson, A. J. (1995). Reintroduction of eastern barred bandicoots at Gellibrand Hill Park, Victoria. In 'Reintroduction Biology of Australasian Wildlife'. (Ed. M. Serena.) pp. 219–25. (Surrey Beatty & Sons: Sydney.)

Franklin, I. R. (1980). Evolutionary change in small populations. In 'Conservation Biology: an Evolutionary–Ecological Perspective'. (Eds M. J. Soulé and B. A. Wilcox.) pp. 135–49. (Sinauer Associates: Sunderland, Massachusetts.)

Gilpin, M. (1991). The genetic effective size of a metapopulation. *Biological Journal of the Linnean Society* **42**, 165–75.

Hanksi, I., and Gilpin, M. (1991). Metapopulation dynamics: brief history and conceptual domain. *Biological Journal of the Linnean Society* **42**, 3–16.

Heinsohn, G. E. (1966). Ecology and reproduction of the Tasmanian bandicoots (*Perameles gunni* and *Isoodon obesulus*). *University of California Publications in Zoology* **80**, 1–107.

Hook, R. A., and Robinson, W. L. (1982). Attitudes of Michigan citizens toward predators. In 'Wolves of the World: Perspectives of Behavior, Ecology, and Conservation'. (Eds F. H. Harrington and P. C. Pacquet.) pp. 382–94. (Noyes Publications: Park Ridge, New Jersey.)

Houston, B. R., Clark, T. W., and Minta, S. C. (1986). Habitat suitability index model for the black-footed ferret: a method to locate transplant sites. *Great Basin Naturalist Memoirs* **8**, 99–114.

Humphries, R. K., and Seebeck, J. H. (1995). Conservation of the eastern barred bandicoot *Perameles gunnii* on private land in Victoria. In 'People and Nature Conservation. Perspectives on Private Land Use and Endangered Species Recovery'. (Eds A. Bennett, G. Backhouse and T. Clark.) pp. 156–62. (Royal Zoological Society of New South Wales: Sydney)

Lande, R., and Barrowclough, G. F. (1987). Effective population size, genetic variation, and their use in population management. In 'Viable Populations for Conservation'. (Ed. M. J. Soulé.) pp. 87–123. (Cambridge University Press: Cambridge.)

Lenghaus, C., Obendorf, D. L., and Wright, F. H. (1990). Veterinary aspects of *Perameles gunnii* biology with special reference to species conservation. In 'Management and Conservation of Small Populations'. (Eds T. W. Clark and J. H. Seebeck.) pp. 89–108. (Chicago Zoological Society: Brookfield, Illinois.)

Minta, S. C., and Clark, T. W. (1989). Habitat suitability analysis of potential translocation sites for black-footed ferrets in northcentral Montana. *Montana BLM Wildlife Technical Bulletin* **2**, 29–45.

Minta, S. C., Clark, T. W., and Goldstraw, P. (1990). Population estimates and characteristics of the eastern barred bandicoot in Victoria, with recommendations for population monitoring. In 'Management and Conservation of Small Populations'. (Eds T. W. Clark and J. H. Seebeck.) pp. 47–75. (Chicago Zoological Society: Brookfield, Illinois.)

Murphy, J. A. (1993). Behaviour of eastern barred bandicoots, *Perameles gunnii* (Marsupialia: Peramelidae), breeding in captivity. *Australian Mammalogy* **16**, 89–92.

Myroniuk, P. (1993). 'Eastern Barred Bandicoot *Perameles gunnii* Captive Breeding Program 1990–1992 Studbook.' (Zoological Board of Victoria, The Royal Melbourne Zoological Gardens: Melbourne.)

Pearce, J. (1994). Preliminary analysis of eastern barred bandicoot (*Perameles gunnii*) habitat preferences. Department of Conservation and Natural Resources, Melbourne.

Reading, R. P., and Kellert, S. R. (1993). Attitudes toward a proposed reintroduction of black-footed ferrets (*Mustela nigripes*). *Conservation Biology* **7**, 569–80.

Reading, R. P., Clark, T. W., Arnold, A. H., Fisher, J. T., Myroniuk, P. O., and Seebeck, J. H. (1992). Analysis of a threatened species recovery programme: the eastern barred bandicoot (*Perameles gunnii*) in Victoria, Australia. Department of Conservation and Environment, Melbourne.

Reading, R. P., Clark, T. W., and Arnold, A. (1994). Attitudes toward the endangered eastern barred bandicoot. *Anthrozoös* **7**, 255–69.

Robinson, N. A., Sherwin, W. B., Murray, N. D., and Graves, J. A. M. (1990). Application of conservation genetics to the eastern barred bandicoot, *Perameles gunnii*. In 'Management and Conservation of Small Populations'. (Eds T. W. Clark and J. H. Seebeck.) pp. 109–29. (Chicago Zoological Society: Brookfield, Illinois.)

Schamberger, M., Farmer, A. H., and Terrell, J. W. (1982). Habitat suitability index models: introduction. United States Department of the Interior, Fish and Wildlife Service/OBS-82/10.

Seebeck, J. H. (1979). Status of the barred bandicoot, *Perameles gunnii*, in Victoria: with a note on husbandry of a captive colony. *Australian Wildlife Research* **6**, 255–64.

Seebeck, J. H. (1990). Recovery management of the eastern barred bandicoot in Victoria: Statewide strategy. In 'Management and Conservation of Small Populations'. (Eds T. W. Clark and J. H. Seebeck.) pp. 165–77. (Chicago Zoological Society: Brookfield, Illinois.)

Seebeck, J. H., and Bowley, G. (1993). Eastern Barred Bandicoot Recovery Program. Gellibrand Hill Park monitoring report, November 1993. Flora and Fauna Branch, Department of Conservation and Natural Resources, Melbourne.

Seebeck, J. H., and Goldstraw, P. (1993). Eastern Barred Bandicoot Recovery Program. Hamilton Community Parkland monitoring report, November 1993. Flora and Fauna Branch, Department of Conservation and Natural Resources, Melbourne.

Seebeck, J. H., and Goldstraw, P. (1995). Eastern Barred Bandicoot Recovery Program. Hamilton Community Parkland monitoring report, October 1994. Flora and Fauna Branch, Department of Conservation and Natural Resources, Melbourne.

Seebeck, J. H., Bennett, A. F., and Dufty, A. C. (1990). Status, distribution, and biogeography of the eastern barred bandicoot. In 'Management and Conservation of Small Populations'. (Eds T. W. Clark and J. H. Seebeck.) pp. 21–32. (Chicago Zoological Society: Brookfield, Illinois.)

Sherwin, W. B., and Brown, P. R. (1990). Problems in the estimation of the effective population size of the eastern barred bandicoot *Perameles gunnii* at Hamilton, Victoria. In 'Bandicoots and Bilbies'. (Eds J. H. Seebeck, P. R. Brown, R. L. Wallis and C. M. Kemper.) pp. 367–74. (Surrey Beatty & Sons: Sydney.)

Soulé, M. J., (1980). Thresholds for survival: maintaining fitness and evolutionary potential. In 'Conservation Biology: an Evolutionary–Ecological Perspective'. (Eds M. J. Soulé and B. A. Wilcox.) pp. 151–69. (Sinauer Associates: Sunderland, Massachusetts.)

United States Fish and Wildlife Service (1980). Habitat evaluation procedures (HEP). United States Fish and Wildlife Service, Division of Ecological Services Manual 102.

United States Fish and Wildlife Service (1981). Standards for the development of habitat suitability index models. United States Fish and Wildlife Service, Division of Ecological Services Manual 103.

Williams, G. L. (1988). An assessment of HEP (Habitat Evaluation Procedures) applications to Bureau of Reclamation projects. *Wildlife Society Bulletin* **16**, 437–47.

Yahner, R. H. (1988). Changes in wildlife communities near edges. *Conservation Biology* **2**, 333–9.

Appendix. Data-collection sheet for gathering expert opinions on habitat suitability for the eastern barred bandicoot

Eastern Barred Bandicoot (*Perameles gunnii*)
Expert Opinion on a Habitat Suitability Index
Data-collection Sheet

Site: ____________________

Location: ____________________

Expert-opinion ratings on suitability indices for the eastern barred bandicoot. Ratings are on a scale of 1–5, where 1 indicates the poorest suitability for bandicoots and 5 indicates the best suitability.

Variable	Rating				
	Poorest				Best
V_3					
PC. Predator Control Potential	1	2	3	4	5
V_5					
FP. Fire Potential[A]	1	2	3	4	5
LS. Local Support	1	2	3	4	5
OS. On-site support (resources)					
P. Managers and Biologists	1	2	3	4	5
E. Money and Equipment	1	2	3	4	5
AV. Availability	1	2	3	4	5

[A]1 = site most likely to experience catastrophic fire, 5 = site least likely.

Manuscript received 3 March 1995; revised and accepted 21 November 1995