Extinction processes in hot spots of avian biodiversity and the targeting of pre-emptive conservation action

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Hot spots of endemism are regarded as important global sites for conservation as they are rich in threatened endemic species and currently experiencing extensive habitat loss. Targeting pre-emptive conservation action to sites that are currently relatively intact but which would be vulnerable to particular human activities if they occurred in the future is, however, also valuable but has received less attention. Here, we address this issue by using data on Endemic Bird Areas (EBAs). First, we identify the ecological factors that affect extinction risk in the face of particular human activities, and then use these insights to identify EBAs that should be priorities for pre-emptive conservation action. Threatened endemic species in EBAs are significantly more likely to be habitat specialists or relatively large-bodied than non-threatened species, when compared across avian families. Increasing habitat loss causes a significant increase in extinction risk among habitat specialists, but we found no evidence to suggest that the presence of alien species/human exploitation causes a significant increase in extinction risk among large-bodied species. This suggests that these particular human activities are contributing to high extinction risk among habitat specialists, but not among large-bodied species. Based on these analyses, we identify 39 EBAs containing 570 species (24% of the total in EBAs) that are not currently threatened with severe habitat loss, but would be ecologically vulnerable to future habitat loss should it occur. We show that these sites tend to be poorly represented in existing priority setting exercises involving hot spots, suggesting that vulnerability must be explicitly included within these exercises if such sites are to be adequately protected.

Keywords: endemic bird areas; extinction risk; habitat loss; alien species; human exploitation

1. INTRODUCTION

Hot spots of endemism are widely regarded as important global sites for conservation because they are rich in restricted-range species that are currently threatened with extinction (Stattersfield *et al.* 1998; Myers *et al.* 2000; Balmford 2002). Hot spots also support disproportionately more evolutionary history than suggested by species' numbers alone (Sechrest *et al.* 2002; see Jansson (2003) for an explanation). Extinction within hot spots is being driven by human activities that primarily result in extensive habitat loss, although introduced alien species and direct exploitation by man are also important factors (Stattersfield *et al.* 1998; Myers *et al.* 2000; Brooks *et al.* 2002). The management of these human activities to reduce their impact, both now and in the future, is one of the key challenges facing conservationists.

Conventionally, priority hot spots for conservation are defined as areas threatened by contemporary human activities (Stattersfield *et al.* 1998; Cincotta *et al.* 2000; Myers *et al.* 2000; Liu *et al.* 2003). However, exclusively focusing on current threats potentially ignores the value of pre-emptive conservation action targeted to areas that are relatively intact but which would be vulnerable to particular human activities if they occurred in the future (see Balmford 1996). This may be important, because currently we have only limited information from threatened areas of high conservation value on habitat regeneration following damage (e.g. Chapman & Chapman 1999;

McLachlan & Bazeley 2001); the ability of management to aid habitat restoration (e.g. Marcano-Vega *et al.* 2002; Duncan & Chapman 2003); and the role of important ecological processes (Balmford *et al.* 1998), which could be dependent, at least in part, on biodiversity (Silver *et al.* 1996; Ganzhorn *et al.* 1999). As a result, pre-emptive conservation action targeted to ecologically vulnerable but largely intact hot spots may represent a very cost-effective, complementary approach to the more expensive and uncertain task of protecting and restoring hot spots under severe current threat (Stattersfield *et al.* 1998; Myers *et al.* 2000). This is a particularly important consideration because increased investment in tropical conservation is urgently required (Balmford *et al.* 2003).

The identification of sites for pre-emptive conservation action depends on understanding the ecological processes driving extinction, since these could be used to identify vulnerable areas. Comparatively little is known, however, about these processes in hot spots, even though we have relatively detailed information on extinction rates in plants and vertebrates, and an understanding of human activities driving extinction (Stattersfield *et al.* 1998; Myers *et al.* 2000; Brooks *et al.* 2002). The key ecological issue is to determine why certain taxa are more vulnerable to extinction than others, and to understand how this risk is affected by human activities. Recent studies have begun to address these issues (e.g. Bennett & Owens 1997; Russell *et al.* 1998; Owens & Bennett 2000; Purvis *et al.* 2000; Reed & Shine 2002). We use data from Endemic Bird Areas (EBAs) to investigate the ecological processes driving extinction, and use these insights to identify priority EBAs for pre-emptive conservation action.

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EBAs are hot spots of global avian biodiversity. A total of 218 EBAs have been identified, defined as areas where the distributions of at least two restricted-range species overlap, which contain 2451 species (93% of all endemic species), over 30% of which are currently threatened with extinction (see Stattersfield *et al.* (1998) for details). EBAs are interesting for studying extinction processes operating in hot spots because collectively they experience several gradients of human activities. Approximately 51% of EBAs are currently experiencing major or severe habitat loss, whereas in 49% current habitat loss is low or moderate; a third of EBAs are threatened by alien species/human exploitation (details given below). Furthermore, most endemic species are found in only one EBA, so ecological characteristics and their exposure to particular human activities are replicated across groups of closely related species, providing a powerful basis for comparative analyses.

We address two specific questions. First, what are the ecological correlates of extinction risk in restricted-range species, and how are these affected by the intensity of particular human activities? Second, how can we use an understanding of these extinction processes to identify EBAs that are currently relatively intact but which are ecologically vulnerable to particular human activities should they occur in the future? Recent work by Owens & Bennett (2000) has shown that the ecological correlates of extinction risk in birds vary depending on the specific human activities involved. They showed that species at risk of extinction because of habitat loss tended to be habitat specialists, whereas species at risk of extinction due to alien species/human exploitation tended to have 'slow' life histories (i.e. relatively large body size). From this, we predicted: (i) that habitat specialists should be significantly more at risk of extinction in EBAs currently experiencing severe habitat loss than in those experiencing low/moderate habitat loss; and (ii) that large-bodied species should be significantly more at risk of extinction in EBAs currently experiencing alien species/human exploitation than in those in which these human activities are absent. We then used these analyses as the basis for identifying priority EBAs for pre-emptive conservation action.

2. MATERIAL AND METHODS

(a) Database

We constructed a database that included 1987 endemic species from 33 avian families inhabiting 178 out of the 218 EBAs identified by Stattersfield *et al.* (1998). EBAs were only included in the database if the degree of habitat loss had been quantified. Stattersfield *et al.* (1998) quantify the degree of habitat loss in EBAs as: severe (estimated as more than 90% of key habitats lost), major (50–90%), moderate (10–50%), limited (0–10%), unquantified (some habitat loss, but no estimate of the amount) and possible (some suspected habitat loss); thus, we excluded EBAs if habitat loss was unquantified. EBAs were also excluded if they contained fewer than two extant endemic species. Most species (1695) are confined to a single EBA.

Endemic species were grouped into families according to the 'tapestry phylogeny' of Sibley & Ahlquist (1990). The extinction risk associated with each species was derived from Stattersfield & Capper (2000). We defined a species as threatened with extinction if it was classified as Critically Endangered, Endangered, Vulnerable or Conservation Dependent (of which there are

only two species, and included because they would (presumably) go extinct if conservation actions were withdrawn). All other species were considered non-threatened. EBAs were excluded if 10% or more of their species were classified as 'data deficient' or 'not evaluated' by Stattersfield & Capper (2000) in order to restrict our analysis only to EBAs for which a reasonably complete set of data on extinction risk was available. To test our explicit predictions about ecological correlates of extinction risk we compiled data on habitat specificity and body mass for as many species as possible. Habitat specificity data were taken from Appendix I in Stattersfield *et al.* (1998), in which each species is given a code representing the broad habitat types in which it occurs. These habitat types are: forest, scrub, savannah, grassland, wetland, desert, rocky areas, agricultural areas, introduced vegetation and unknown. The number of habitat types occupied by each species was calculated, and used in our analysis as a measure of habitat specificity ranging from 1 (habitat specialist) to possibly 9 (habitat generalist) (note species were excluded if their habitat type was 'unknown'). Body mass data (g) were taken from Dunning (1992), and we used female-specific mass whenever possible (Owens & Bennett 2000).

(b) Analysis of extinction processes

To account for phylogenetic dependence in the ecological data for individual species (Harvey & Pagel 1991), we based our analysis on within-family contrasts. To examine whether habitat specificity influences extinction risk at different levels of habitat loss, we first classified EBAs into those currently experiencing severe habitat loss (the categories 'major' and 'severe') and those experiencing low/moderate habitat loss (the categories 'possible', 'low' and 'moderate'; see above for definitions). We aggregated EBAs in this way because a finer scale analysis would have severely reduced the number of families available for analysis in particular habitat loss groups. For each family, we calculated the difference in mean habitat specificity between threatened and non-threatened species for each habitat loss group separately by subtracting the mean value for threatened species from the mean value for non-threatened species. A positive value, therefore, means that threatened species have greater habitat specificity than non-threatened species (i.e. they occupy fewer habitat types), and a negative value means the opposite trend. We tested whether the difference score for each habitat loss group was consistently positive or negative across families by using a one-sample *t*-test with a null hypothesis of zero. To examine whether the difference score changed significantly with increasing habitat loss, we compared the difference scores between habitat loss groups at the family level by using a paired *t*-test.

We adopted a comparable approach to determine whether body mass influences extinction risk. We first divided EBAs into two categories: those in which alien species or human exploitation occurred, and those in which these threats were absent, based on the individual EBA descriptions given in Stattersfield *et al.* (1998). For each family, we calculated the difference in mean body mass between threatened and non-threatened species for each group of EBAs by first dividing the body mass means by the standard deviation in body mass for each family, then subtracting the mean value for non-threatened species from the mean value for threatened species. We divided means by the standard deviation to make the resulting difference scores comparable across families that differed considerably in body mass. A positive value means that threatened species have larger body mass than non-threatened species, and a negative value means the opposite trend. We tested whether the difference score for

each EBA group varied consistently between families by using a one-sample *t*-test with a null hypothesis of zero. To examine whether the difference score changed significantly in the presence of alien predators/human exploitation, we compared the difference scores between these groups at the family-level by using a paired *t*-test. Note that there are few body mass data for threatened species in Dunning (1992), so the body mass analysis was limited to 13 families for which sufficient data were available (i.e. for which there were a minimum of two body mass records each for threatened and non-threatened species in a particular EBA group). Families included in the body mass analysis were the Accipitridae, Phasianidae, Columbidae, Psittacidae, Strigidae, Trochilidae, Formicariidae, Tyrannidae, Maluridae, Corvidae, Muscicapidae, Sturnidae and Fringillidae.

3. RESULTS

(a) Extinction processes

There was no evidence to suggest that the extent of habitat loss and the presence of alien species/human exploitation covaried across EBAs ($\chi^2 = 1.02$, $p < 0.25$, d.f. = 1). Whereas 18.5% (33 out of 178) of EBAs are experiencing both severe habitat loss and the presence of alien species/human exploitation, 34.8% (62 out of 178) are experiencing neither threat. EBAs experiencing severe and low/moderate habitat loss are approximately equally common (50.6% and 49.4%, respectively), whereas only 33.1% (59 out of 178) of EBAs are currently threatened by the presence of alien species/human exploitation.

In both habitat loss groups, threatened species showed a significantly greater degree of habitat specificity than non-threatened species (one-sample *t*-tests; low/moderate habitat loss: $t = 2.07$, $p = 0.047$; severe habitat loss: $t = 4.52$, $p < 0.001$; $n = 33$ families in both cases; figure 1a). This difference increased significantly as the extent of habitat loss became more severe (paired *t*-test: $t = 2.08$, $p = 0.046$, $n = 33$ families; figure 1a). To examine how habitat specificity influences extinction risk in more detail, we calculated the proportion of threatened species in each habitat specificity category within each family, and compared these between EBAs experiencing low/moderate and severe habitat loss (figure 1b). Among species occupying a single habitat type, the proportion of threatened species within families increased significantly as habitat loss became more severe (paired *t*-test based on family values; $t = 3.18$, $p = 0.002$, $n = 33$ families), but no significant changes occurred for those occupying two ($p = 0.27$), or three or more ($p = 0.74$) habitat types (figure 1b). Therefore, as habitat loss becomes more severe, the extinction risk of habitat specialists increases.

Threatened species had a higher body mass than non-threatened species, although this difference was only statistically significant in EBAs that had alien species/human exploitation (figure 2) (one-sample *t*-tests; EBAs without alien species/human exploitation: $t = 1.41$, $p = 0.18$; EBAs with alien species/human exploitation: $t = 3.64$, $p = 0.004$; $n = 13$ families in both cases). The difference scores between the EBAs with and without alien species/human exploitation were similar (paired *t*-test: $t = -0.17$, $p = 0.87$, $n = 13$ families; figure 2), suggesting that the increased extinction risk of restricted-range species with relatively large body size is not significantly affected by human activities. We also checked to see

Figure 1. (a) Differences in the degree of habitat specificity between threatened and non-threatened species occurring in EBAs currently experiencing low/moderate or severe habitat loss. Each bar shows the mean value of 33 within-family contrasts $\pm$ 95% confidence interval. Positive values mean that threatened species are found in a smaller number of habitats (i.e. have greater specificity) than non-threatened species. *p*-Values associated with the one-sample *t*-tests (see text) are shown on the bars: * $p < 0.05$, *** $p < 0.001$. (b) The proportion of threatened species in different habitat specificity groups (a value of 1 means the species occupies a single habitat type, etc.) for EBAs currently experiencing low/moderate (light grey bars) or severe (dark grey bars) habitat loss. Each bar shows the mean value for 33 families $\pm$ 1 s.e.m.

whether the within family body-size contrasts varied along the habitat loss gradient. This analysis showed that threatened species had significantly higher body mass than non-threatened species in both habitat loss groups (one-sample *t*-tests; low/moderate habitat loss: $t = 2.2$, $p = 0.048$; severe habitat loss: $t = 2.48$, $p = 0.029$; $n = 13$ families in both cases), but there was no significant increase in the contrasts as habitat loss became more severe (paired *t*-test: $t = -0.18$, $p = 0.86$, $n = 13$ families). Therefore, neither alien species/human exploitation nor habitat loss appears to affect extinction risk in relation to body size. Across all EBAs, threatened species had significantly higher body mass than non-threatened species (one-sample *t*-test on within-family contrasts: $t = 2.70$, $p = 0.019$, $n = 13$ families).

Figure 2. Differences in body mass (standard deviation units) between threatened and non-threatened species occurring in EBAs currently experiencing alien predators/human exploitation and those not experiencing this threat. Each bar shows the mean value of 13 within-family contrasts $\pm$ 95% confidence interval. Positive values mean threatened species are larger-bodied than non-threatened species. p -Values associated with the one-sample t -tests (see text) are shown on the bars: n.s., not significant, ** $p < 0.01$.

(b) Identifying priority EBAs for pre-emptive conservation action

We limited this analysis to the 88 EBAs currently experiencing low/moderate habitat loss. To prioritize among these 88 EBAs we used two axes (see also Margules & Pressey 2000). First, we used the number of endemic species within each EBA as a measure of its biological value. Second, we used the estimated proportion of threatened species in the face of future habitat loss as a measure of its ecological vulnerability. To estimate this proportion we firstly estimated a predicted probability of becoming threatened in the face of severe future habitat loss for each habitat specialist species (i.e. species occupying a single habitat type). To do this, we assumed that the probability for each species was equivalent to the proportion of threatened habitat specialist species found within its family in EBAs currently experiencing severe habitat loss (see figure 1b). Second, we assumed that the probability for all other species was equivalent to the proportion of threatened species within its family and habitat specificity group in EBAs currently experiencing low/moderate habitat loss, because we found no evidence to suggest that extinction risk would increase if habitat loss increased among these groups (see figure 1b). In this way, we produced a predicted probability of becoming threatened for each species in the face of future severe habitat loss. Finally, we averaged these probabilities across all species within each of the 88 EBAs to obtain a measure of the vulnerability of each EBA to future severe habitat loss. This is equivalent to estimating the expected proportion of threatened species within each EBA if habitat loss in the future increases significantly.

The resulting assessment is shown in figure 3. EBAs in priority group I have higher than average numbers of endemics and are ecologically more vulnerable than aver-

Figure 3. Identifying high priority EBAs in relation to their vulnerability to future habitat loss. Each point on the graph is an EBA ($n = 88$) currently experiencing low/moderate habitat loss. The number of endemic species is used as an axis of biological importance. The estimated mean proportion of threatened species in each EBA in the face of severe future habitat loss is used as an axis of ecological vulnerability to habitat loss. The mean value across all EBAs is shown on the graph for each axis, and is used to divide EBAs into four priority groupings from I (highest priority) to IV (lowest priority) (also see text for details). Priority I (grey circles); priority II (grey squares); priority III (grey triangles) and priority IV (open circles).

age to severe habitat loss. EBAs in priority group II are ecologically more vulnerable than average, but have fewer than the average number of endemics. EBAs in priority groups III and IV have a lower than average ecological vulnerability to future habitat loss, but vary in terms of the number of endemics. To target pre-emptive conservation action to the most vulnerable EBAs, priority groups I and II should be considered the highest priority. Details of the EBAs in these groups are shown in table 1. They contain 570 endemic species in total, which represents 24% of the total number found in all 218 EBAs.

4. DISCUSSION

(a) Extinction processes

Our results show that both habitat specificity and large body size are associated with increased levels of extinction risk among endemic bird species, and habitat specificity predisposes species to an increased risk of extinction in the face of habitat loss. Our results on habitat specificity are consistent with the findings of Owens & Bennett (2000) as they show that specific anthropogenic causes of extinction (habitat loss) have a differential impact on species, depending on their ecological characteristics (habitat specificity). The most plausible explanation for these patterns is that habitat specialists have narrower niche requirements, and habitat loss disproportionately reduces niche availability in such species (e.g. Brown & Maurer 1989; Bibby 1995; Owens & Bennett 2000).

By contrast, we found no evidence to suggest that the elevated risk of extinction associated with large body size was affected by alien predators/human exploitation. What might cause this pattern? First, the results of this analysis

Table 1. Ecologically vulnerable EBAs. (The table shows sites ranked as I or II based on the assessment shown in figure 3. It gives details of each EBA from Stattersfield *et al.* (1998), and compares their spatial overlap with the Biodiversity Hot spots of Myers *et al.* (2000).)

reference number	Endemic Bird Area		biodiversity hot spots ^c				
	region	name	priority ranking ^a	number of species	area (km ²)	EBA priority ^b	inside a hot spot? hot spot name
20	North and Central America	Costa Rica and Panama Highlands	I	52	23000	urgent	yes Mesoamerica
24		Darién Highlands	I	16	3000	high	no
33	South America	Cordillera de la Costa Central	I	17	6200	high	no
44		Ecuador-Peru East Andes	I	17	28000	high	yes tropical Andes
49		northeast Peruvian cordilleras	I	24	37000	urgent	yes tropical Andes
55		Bolivian and Peruvian upper yungas	I	20	35000	urgent	yes tropical Andes
64		Tepuis	I	38	57000	urgent	no
166	South East Asian Islands, New Guinea and Australia	Sulawesi	I	54	190000	high	yes Wallacea
168		Banggai and Sula Islands	I	16	7200	high	yes Wallacea
172		West Papuan lowlands	I	19	110000	high	no
182		Queensland wet tropics	I	16	32000	urgent	no
195	Pacific Islands	New Britain and New Ireland	I	54	48000	high	no
198		Solomon group	I	78	34000	critical	no
10	North and Central America	northern Sierra Madre Oriental	II	2	15000	high	no
16		Cozumel Island	II	4	490	urgent	no
19		central American Caribbean slope	II	12	120000	high	yes Mesoamerica
23		Darién Lowlands	II	13	61000	critical	no
47	South America	Andean ridge-top forests	II	7	3800	urgent	yes tropical Andes
53		Peruvian East Andean foothills	II	14	32000	high	yes tropical Andes
63		Rio Branco gallery forest	II	2	94000	urgent	no
65		Orinoco-Negro white-sands forest	II	12	62000	high	no
67		Amazon flooded forests	II	4	140000	high	no
68		southeast Peruvian lowlands	II	12	260000	urgent	no
79	Africa, Europe and Middle East	Tristan Islands	II	4	110	urgent	no
80		Gough Island	II	2	65	urgent	no
96		west Malagasy wetlands	II	7	26000	critical	yes Madagascar
107		eastern Zaïre lowlands	II	6	75000	high	no
125	continental Asia	Andaman Islands	II	12	8200	high	yes south-central China
126		Nicobar Islands	II	9	1800	high	yes Sundaland

(Continued.)

Table 1. (Continued.)

reference number	Endemic Bird Area		priority ranking ^a	number of species	area (km ²)	EBA priority ^b	biodiversity hot spots ^c	
	region	name					inside a hot spot?	hot spot name
181	South East Asian Islands, New Guinea and Australia	Cape York	II	5	99000	critical	no	
183		eastern Australia	II	10	160000	critical	no	
185		Tasmania	II	14	68000	urgent	no	
187		northwest Australia	II	13	560000	urgent	no	
188		Christmas Island	II	2	140	high	yes	Sundaland
204	Pacific Islands	Lord Howe Island	II	2	17	critical	no	
207		South Island of New Zealand	II	6	110000	urgent	yes	New Zealand
208		Auckland Islands	II	2	610	high	yes	New Zealand
209		Chatham Islands	II	5	970	critical	yes	New Zealand
214		Tuamotu archipelago	II	8	690	critical	yes	Polynesia/Macronesia

^a Based on figure 3, this study.^b From Stattersfield *et al.* (1998).^c Based on Myers *et al.* (2000).

may lack statistical power because data are only available for about one-third of the avian families in EBAs (see § 2). It is at least possible that alien predators/human exploitation may elevate the extinction risk of large-bodied species but this effect might only be detectable if body mass data were available for a greater range of species and families. For this reason, the lack of statistical significance should be interpreted with caution. Second, it is also possible that although alien predators/human exploitation are present in a third of EBAs, they have only a very limited ecological impact on extinction risk across a broad range of species in relation to their ecological characteristics. If this is the case, then the elevated extinction risk associated with large body size may be due, primarily, to other ecological characteristics of such species, such as low population densities or larger home ranges (e.g. Purvis *et al.* 2000; Woodroffe & Ginsberg 2000). This interpretation does not dismiss the importance of alien predators/human exploitation in causing elevated extinction risk in particular species, but our analysis provides no clear evidence to suggest that, across a broad range of species, body size plays a significant role in predisposing species to this threat.

(b) *Targeting pre-emptive conservation action*

There is an ongoing debate among conservationists about identifying global conservation priorities at an international level, and little consensus about the specific approach that should be adopted (Mace *et al.* 2000). A part of this debate concerns how the degree of threat should be incorporated within priority-setting exercises (see also Balmford 1996; Margules & Pressey 2000). For hot spots of endemism, threat assessment is usually based on the degree to which hot spots are threatened by contemporary human activities (Stattersfield *et al.* 1998; Cincotta *et al.* 2000; Myers *et al.* 2000; Liu *et al.* 2003). However, focusing exclusively on current threats may mean that such assessments ignore the conservation value of relatively intact sites that are ecologically vulnerable to particular human activities should they occur in future. This may be important, particularly because we currently have only a limited idea about the feasibility of habitat restoration and species recovery within hot spots currently experiencing relatively severe habitat loss, and other damaging human activities. Furthermore, targeting conservation action to vulnerable but intact sites is a more cost-effective option than only acting once they are threatened (see Balmford *et al.* 2003).

It remains possible, however, that current priority-setting exercises for hot spots of endemism are sufficiently comprehensive that ecologically vulnerable sites are adequately represented. To test this possibility we examined overlap between our ecologically vulnerable EBAs, the priorities outlined by Stattersfield *et al.* (1998) for EBAs and the biodiversity hot spots identified by Myers *et al.* (2000) (table 1). Stattersfield *et al.* (1998) provided a priority ranking for each EBA (critical, urgent and high) based on biological importance and the degree of threat. There is a significant difference between the frequency of EBAs in these groups among the ecologically vulnerable EBAs identified in table 1 and the remaining EBAs ($\chi^2 = 4.35$, $p < 0.05$, d.f. = 2). This arises because the frequency of 'critical' EBAs is lower in the ecologically

vulnerable EBAs (21%) compared with the remaining EBAs (42%). Only 43.5% of the ecologically vulnerable EBAs, which include 257 endemic species (45.1%), occur within the biodiversity hot spots identified by Myers *et al.* (2000) (table 1). This is significantly lower than the 68% overlap between EBAs as a whole and the hot spots ($\chi^2 = 10.68$, $p < 0.01$, d.f. = 1). Although for several EBAs the geographical separation is relatively minor (so that conservation efforts for hot spots might also affect adjacent EBAs), this is not the case for parts of South America (EBAs: 33, 63, 64, 65, 67), New Guinea and its neighbouring islands in the Pacific (EBAs: 172, 195, 198) and Australia (EBAs: 181, 182, 183, 185). We conclude, therefore, that existing priority-setting exercises for hot spots of endemism under-represent ecologically vulnerable sites.

If one of the goals of conservation planning is to provide protection for relatively intact sites that may suffer disproportionate species loss if particular human activities occur in the future, then our analyses show that ecological vulnerability needs to be included explicitly within priority-setting exercises involving hot spots. Our analysis of ecological factors that affect extinction risk and predispose certain species to particular anthropogenic causes of extinction, illustrates how relatively simple ecological concepts can be used to identify vulnerable sites and target pre-emptive conservation action. We should see relatively intact but ecologically vulnerable areas as a means of providing opportunities to conserve the ecological and evolutionary contemporaries of threatened species occupying sites that are themselves currently threatened. Given the current uncertainties in our ability to reduce current human impacts and restore damaged ecosystems, targeting pre-emptive conservation action to ecologically vulnerable sites seems a pragmatic and cost-effective way of complementing global 'fire-fighting' efforts to save the most threatened species and sites (see also Mittermeier *et al.* 2003). In our view, initiatives that do not place an exclusive emphasis on current threats, such as the Global 200 Ecoregions (Olson & Dinerstein 1998) and Wilderness Areas (Mittermeier *et al.* 1998, 2003), may be able to play an important role in this respect.

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