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What works for threatened species recovery? An empirical evaluation for Australia

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Abstract Despite the growing numbers of threatened species and high levels of spending on their recovery worldwide, there is surprisingly little evidence about which conservation approaches are effective in arresting or reversing threatened species declines. Using two government data sets, we examined associations between population trends for 841 nationally-threatened terrestrial species in Australia, and four measures of conservation effort: (a) how much their distribution overlaps with strictly protected areas (IUCN I–IV), (b) and other protected areas (IUCN V–VI), (c) the number of recovery activities directed at the species, and (d) numbers of natural resource conservation activities applied in areas where populations of the threatened species occur. We found that all populations of 606 (72%) species were in decline. Species with greater distributional overlap with strictly protected areas had proportionately more populations that were increasing or stable. This effect was robust to geographic range size, data quality differences and extent of protection. Measures other than strictly protected areas showed no positive associations with stable or increasing trends. Indeed, species from regions with more natural resource conservation activities were found to be more likely to be declining, consistent with differential targeting of such generalised conservation activities to highly disturbed landscapes. Major differences in trends were also found among the different jurisdictions in which species predominantly occurred, which may be related to different legislative protections against habitat destruction. Although we were not able to test causation, this research corroborates other evidence that protected areas contribute to the stabilization or

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recovery of threatened species, and provides little empirical support for other conservation approaches.

Keywords Threatened species · Empirical evaluation · Protected areas · Population trends · Natural resource management · Recovery actions

Introduction

Almost every country on Earth faces a growing list of species at risk of extinction, declining habitat extent and condition, chronic under-funding of conservation and uncertainty about the likelihood of success of conservation effort (Hails et al. 2009; IUCN 2010). Given the typically limited resources available and the short timeframes in which action is needed, focusing on interventions that are proven to be effective is desirable (Bottrill et al. 2008; 2009). Many authors have called for greater accountability of conservation efforts and empirical evaluation of effectiveness (Ferraro and Pattanayak 2006; Segan et al. 2010). Unfortunately, there are still very few examples of empirical evaluations of conservation interventions in terms of species recovery outcomes, and none at all that compare the effectiveness of alternate approaches.

In this study, we evaluated how effective alternate conservation activities have been for threatened species recovery in Australia at a continental scale. Australia is one of few suitable case studies available to do this, because there is a national data set for both species trends and conservation activities (Sattler and Creighton 2002). As for many developed countries Australia has had widespread loss or degradation of natural habitats and natural ecological processes (Woinarski et al. 2007; Lindenmayer et al. 2008). As a result 13% of Australia's known terrestrial vertebrate species are now formally listed as threatened under Australia's national species legislation (The "Environmental Protection and Biodiversity Conservation Act" or EPBCA; Department of the Environment Water Heritage and the Arts 2009a). Many other native species not yet considered threatened have collapsing distributions and ongoing declines in abundance (Mackey et al. 2008; Kingsford et al. 2009).

Government and non-government organizations have pursued diverse conservation activities to promote threatened species recovery over the past several decades. These can be divided into two major approaches: first, change in the primary land-use by establishing protected areas (either strictly protected or less strictly protected); and second, short-term changes in the way land is managed without necessarily changing land use through direct interventions such as species-specific recovery actions, or "natural resource management" activities.

Australia spent over $2.5 billion financing such actions from 1992 to 2008 (Department of the Environment Water Heritage and the Arts 2007) in the absence of guidance from empirical evaluation of the effectiveness of the different conservation approaches. By analyzing population trends for threatened species across Australia against the different kinds of management interventions mentioned above, we provide the first evaluation of what has been working and what has been not, for threatened species recovery. To our knowledge, this represents the first attempt in the literature to evaluate alternative conservation actions based on population outcomes for threatened species at a continental scale.

Methods

Threatened species population trends

In 2002, the Australian government produced the first national Terrestrial Biodiversity Assessment ("Assessment" hereafter; Sattler and Creighton 2002), containing 13,858 records of trends for populations of threatened species within 385 spatially defined subbioregions of Australia (hereafter "subregion"; Environment Australia 2000). Trend data were based on quantitative evidence such as field measurement, or qualitative methods, primarily the consensus opinion of panels of 40 experts from different areas of taxonomic and geographic expertise (Sattler and Creighton 2002). We discarded globally extinct species as well as populations lacking trend records, those whose distributions were poorly mapped, those not listed as threatened under national legislation, marine species, and subsurface cave-specialist fauna not expected a priori to show significant dependence on protection of the land surface. This left a sample of 841 species with known trends in one or more subregional populations (698 plants, 143 animals).

We simplified the existing multi-category variable describing population trends for each species population within each subregion to a binary variable equal to one for increasing or stable trends, and equal to zero for populations in decline, rapidly declining or extinct in the subregion. For each species, we calculated the proportion of subregional populations with a known trend for which trend was increasing or stable (*IS*).

Geographic distribution overlap with protected areas

We utilised the Species of National Environmental Significance (SNES) spatial database (Department of the Environment Water Heritage and the Arts 2008c). This database consists of mapped distribution polygons for each species officially recognised as critically endangered, endangered or vulnerable to extinction under national legislation.

Distributional data are of highly variable quality and were derived using variety of methods. Following Watson et al. (2010) we used only polygons where a species was classed as "known" or "likely to occur". We intersected these presumed geographic distributions for each species with the distributions of the protected area system in 2006 (Department of the Environment Water Heritage and the Arts 2008b), and calculated the amount of overlap with strictly protected areas (*SPA*: IUCN management categories I–IV; Dudley 2008) and other protected areas (*OPA*: IUCN management categories V and VI; Dudley 2008).

Conservation effort other than protected areas

We calculated the mean number of recovery actions other than establishing protected areas (*RA*) undertaken for each species in the subregions in which the species occurs, using data provided in the Assessment. Recovery actions fell into 20 categories including such activities as protected areas, education, fencing, fire, pest, weed, grazing and visitor management activities (Sattler and Creighton 2002). The Assessment database also documents 7,632 "natural resource management" (NRM) actions that had been applied in different subregions, sorted into ten categories including incentives, industry voluntary practice codes, threat abatement, catchment and property planning. These activities are similar to many of the recovery actions, but are not specifically directed toward any particular species within a given subregion. Based on the text description of each NRM activities in each subregion, those that were clearly conservation-oriented (such as threat abatement), as opposed to planning, research or production-oriented, were summed to produce a total for each subregion. We then calculated the mean number of such conservation-oriented NRM actions (*CM*) across all subregions in which each species had a known population trend. There were missing values for 20 subregions, and for 39 species with populations falling only in these subregions, all from Western Australia. The overall mean of *CM* was used to impute the missing values in these cases. As this imputation method can bias the relationship with population trends, we tested the robustness of our results by performing analyses with and without using these imputed missing values (Little and Rubin 1987).

Other covariates

To reduce the chance that key covariates were driving correlations we tested for interaction of regressions with geographic range size, since for many narrowly-distributed species, the present day known or likely to occur distribution may be the legacy of distribution contraction, the very reason the species is considered threatened. To determine whether large- and small-distribution species showed different effects, we included a binary variable *R50* in the analysis, taking a value of 1 and 0 respectively for species with geographic distribution sizes above and below the median distribution size of 22,179 ha.

As level of endangerment is expected to be a major determinant of species population trends, we included a binary variable *Status*, equal to zero if the species is classified as critically endangered or endangered under the EPBCA, or equal to one if vulnerable. Taxonomic group was also included as a categorical variable (*Taxon*) with four groups: plants, birds, mammals and other animals pooled due to small sample sizes (amphibians, invertebrates, reptiles, fish). An interaction term of *Taxon* × *SPA* was tested in regression, since we expected the regression of trend on strictly protected areas to be taxon-dependent based on previous studies (Baillie et al. 2004). Finally, we included the categorical variable *Jurisdiction*, classifying each species into the province in which its geographic distribution predominantly falls: New South Wales (including the Australian Capital Territory), Northern Territory, Queensland, South Australia, Tasmania, Victoria and Western Australia. This was done because the states and territories are largely responsible for native species conservation and protected area establishment and management in Australia, and all have their particular legislative systems. The federal government plays a comparatively minor role by providing funding incentives for addition of new protected areas, and helping to develop national strategies (Department of the Environment Water Heritage and the Arts 2009b).

Spatial and statistical analysis

Using these data, we calculated the proportion of populations of threatened species that were increasing or stable, and tested for correlations with (a) how much their distribution overlaps with strictly protected areas (IUCN I–IV), (b) and other protected areas (IUCN V–VI), (c) the number of recovery activities directed at the species, and (d) numbers of natural resource conservation activities applied in areas where populations of the threatened species occur.

Proportions of area protected (*SPA, OPA*) were arcsin-$\sqrt{}$ transformed to normalise distributions. Count data (*RA*, *CM*) were square root transformed to normalise distributions

(Sokal and Rohlf 1995). We fitted logistic regressions using the Stata version 8 (StataCorp 2003) General Linear Model subroutine, with a binomial logit error function for the binary trend variable. Independent variables were tested stepwise by likelihood ratio tests against models with those variables removed, and a final model was subsequently developed including only significant variables.

Results

Declines overwhelmingly dominated species trends, with 606 (72%) of the 841 species declining, or rapidly declining in all of their subregional populations, while 12% had some but not all populations with increasing or stable trends, and finally, 16% had all populations showing increasing or stable trends (*IS*). Endangered (including critically endangered) species were significantly less likely to be stable or increasing than vulnerable species (Tables 1, 2).

Species with greater spatial overlap with strictly protected areas (*SPA*) were more likely to be stable or increasing ($P < 0.001$). There was no significant regression of trends on overlaps with other types of protected areas (*OPA*) (Table 1).

The final model predicted a 2.3-fold increase in the likelihood a species was stable or increasing from 15 to 35%, for an increase from zero to 93% of the distribution

Table 1 Stepwise fitting of logistic regression models to proportions of subregional populations increasing or stable (*IS*) for 841 threatened species

Independent variable	Sign	Test versus null	Test versus full	Final model
Strict PA overlap *SPA*	+	$P < 0.001$	$P = 0.002$	$P < 0.001$
Other PA overlap *OPA*	–	$P < 0.001$	$P = 0.298$ removed	
No. recovery actions *RA*	n/a	$P = 0.200$ removed		
NRM actions *CM*	–	$P < 0.001$[a]	$P < 0.001$	$P < 0.001$
Distribution over/under median *R50*	n/a	$P = 0.188$ removed[b]		
Interaction	n/a	$P = 0.507$ removed		
Taxon	n/a	$P = 0.125$ removed		
Birds versus others	n/a	$P = 0.379$ removed		
Interaction	n/a	$P = 0.595$ removed[b]		
Mammals versus others	+	$P = 0.031$	$P = 0.323$ removed	
Status	+	$P = 0.014$	$P = 0.002$	$P = 0.004$
Jurisdiction	n/a	$P < 0.001$	NSW $P < 0.001$ NT $P = 0.209$ removed Qld $P = 0.044$ SA $P = 0.666$ removed Tas $P = 0.006$ Vic $P = 0.036$	NSW P < 0.001 Qld $P = 0.066$[c] Tas $P < 0.001$ Vic $P < 0.001$

All probabilities shown are for likelihood ratio tests of models with effect, against models with that effect removed

[a] $P < 0.001$ both excluding missing values $N = 802$, and also including missing values imputed with the grand mean for all species

[b] All interactions tested against a non-null model including both main effects

[c] Retained despite marginal significance level

overlapping strictly protected areas (the mean *SPA* for the top decile of species; Fig. 1; Table 1). Nevertheless, 65% of species were predicted to still be in decline under this statistical model, even if they had, on average, 93% of their distribution protected (Fig. 1).

Species in areas subject to more natural resource conservation actions (*CM*) were significantly less likely to be increasing/stable than otherwise (Table 1). There were also major differences among jurisdictions in proportions of species declining. Species predominantly in NSW, Queensland and Tasmania were significantly less likely to be increasing or stable than other species, while species in Victoria, one of the most agriculturally developed states, were significantly more likely to be increasing or stable (Table 2).

No significant interaction between *SPA* and distribution extent was found in the regression (*R50*, Table 1).

We tested for taxonomic interaction with *SPA* for a plant/animal contrast, and a contrast of birds versus all other species. The latter was specifically tested to allow comparison with Baillie et al. (2004), who reported a marked contrast between birds and amphibians in the association between trends and overlap with protected areas. However, neither taxonomic differences nor interactions with *SPA* were significant in regressions in this study. Mammals appeared higher than other species in proportions increasing or stable (Table 2). However, this difference was non-significant when other covariates were included in the model, mostly likely due to the confounding of taxon with other covariates such as jurisdiction (Table 1).

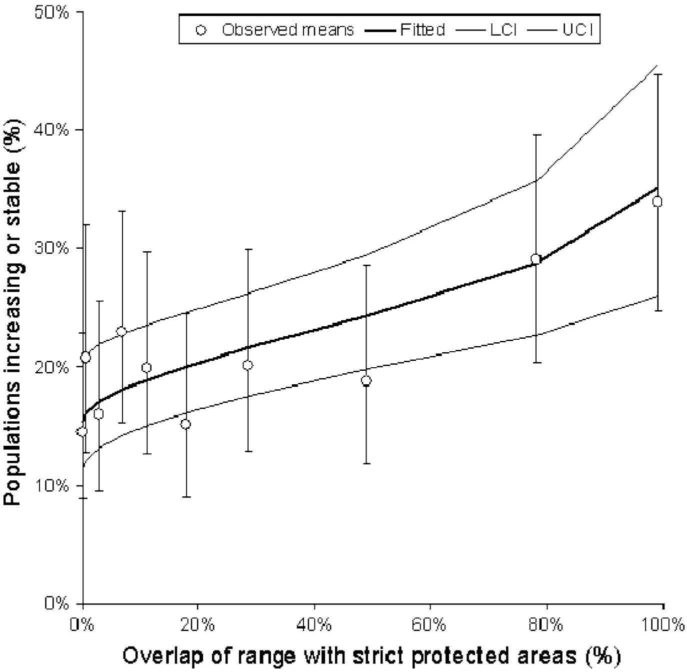

Fig. 1 Observed proportions of species stable or increasing for plants and animals, means with binomial 95% confidence limits, for deciles of overlap of distributions with strictly protected areas. Also shown is the fitted logistic regression with upper and lower 95% confidence limits (*UCI*, *LCI*)

Table 2 Proportions of populations increasing or stable for different taxonomic and status classes and jurisdictions, means and 95% confidence intervals

Variable	Categories	*N*	Mean (%)	LCI (%)	UCI (%)
Taxon	Plants	698	20.0a	17.2	23.1
	Birds	43	26.5a	15.5	41.5
	Mammals	43	34.8a	22.2	50.0
	Other animals	57	18.6a	10.5	30.8
Status	Endangered	399	17.4b	14.0	21.4
	Vulnerable	442	24.2c	20.5	28.5
Jurisdiction	NSW	242	3.4d	1.7	6.6
	NT	16	22.5e	8.2	48.4
	Qld	101	14.2f	8.7	22.5
	SA	44	36.3e	23.6	51.3
	Tas	80	11.2f	5.9	20.2
	Vic	109	52.6g	43.2	61.7
	WA	249	27.4e	22.2	33.2

Means of categories within variables followed by different letters were significantly different at $P > 0.05$ in post-regression pairwise tests with Bonferroni correction

The regression of *IS* on *SPA* remained highly significant when using robust standard errors and clustering on taxonomic family to account for possible phylogenetic autocorrelation ($P = 0.005$) and also after discarding all species except the 437 for which trend data were based at least in part on quantitative rather than solely qualitative or unknown quality data ($P = 0.028$). The regression of *IS* on *SPA* also remained significant after discarding the 85 species in the top decile of *SPA* ($P = 0.027$). An orthogonal quadratic *SPA* term was not significant in regression, indicating that the relationship was simple linear (in the logit: arcsin$\sqrt{}$- transformed scale), rather than a non-linear relationship with stronger correlation at higher *SPA* levels than at lower levels.

Discussion

Over the past two decades there has been growing movement away from protected areas as the primary approach to arresting biodiversity loss in some countries. Emphasis has shifted to natural resource management ("NRM") or "stewardship" activities that do not change the primary land use, only the way the existing land-use is conducted (Kalamandeen and Gillson 2007; Gaston et al. 2008). The Australian Government for example, currently devotes only about 10% of its total conservation budget on expansion of protected areas (Department of the Environment Water Heritage and the Arts 2008a) although this represents an increase above the level of 3% per annum over several preceding years. Critics of protected areas cite the generation of conflicts with land and water users (Vanclay 2001; Wilshusen et al. 2002; Agardy et al. 2005; Kaiser 2005; Pearce et al. 2005), that protected areas are often placed in areas already at little genuine risk of loss (Ferraro and Pattanayak 2006; Joppa and Pfaff 2009) and that the expansion of protected areas has been too slow to counter pervasive habitat destruction (McDonald-Madden et al. 2009).

There is some empirical evidence that protected areas work for threatened species. Tropical protected areas have significantly reduced levels of threats from burning, hunting, logging, and livestock in comparison with unprotected areas immediately adjacent (Bruner et al. 2001). Marine protected areas show higher total marine species richness (Halpern and Warner 2003; Stewart et al. 2009; Selig and Bruno 2010) compared with comparable unprotected areas. Among amphibian species entirely outside protected areas, proportionately more are declining than among those overlapping protected areas, although birds show the opposite pattern, a result that remains unexplained (Baillie et al. 2004). However, there are no other studies that compare different approaches with protected areas in terms of population outcomes.

In this study, among the four candidate measures of conservation effort, spatial overlap with strictly protected areas or other protected areas, number of recovery actions and number of resource conservation actions, only overlap with strictly protected areas was robustly associated with stable or increasing threatened species trends. Ferraro and Pattanayak (2006) questioned whether protected areas are effective in protecting habitats and species and called for empirical evaluation. Our results present the first empirical support at a continental scale for strictly protected areas as a means to ameliorate population declines of threatened species over other approaches such as less secure protected areas, and non-protected area-related recovery actions or natural resource conservation activities.

This result is correlative. Clearly without genuine experimental design, we cannot evaluate causation. Indeed causation could have been in either direction. It is possible that trend scores assigned by experts could have been influenced by knowledge of protected area overlaps of species' distributions. However, there are two reasons why we consider this explanation unlikely. First, the correlation remained highly significant after excluding species with trend data derived solely from expert opinion, and second, more than 40 experts were used in panels developing qualitative trend scores, making concerted bias unlikely (Sattler and Creighton 2002). Another possibility is that stabilizing species trends are associated with protected areas because they are placed in areas of little genuine risk of loss (Joppa and Pfaff 2009). Whether particular Australian protected areas have or have not genuinely prevented losses that might otherwise have occurred is not a question that could be addressed here with the data available. Threatened species are however over-represented in Australian protected areas compared with random protected areas of the same size (Watson et al. 2010), and one of the reasons why this might be so, is that threatened species have been lost elsewhere in the landscape, suggesting that protected areas have on average been effective in preventing habitat loss that might otherwise have occurred.

The contribution of protected areas to species recovery might be expected to depend on ecology and life history of species. For example, smaller, habitat specialist birds are more likely to be at risk of extinction from habitat loss, while larger, slow reproducing species are more at risk from direct persecution and exotic predators (Owens and Bennett 2000). However, this study found no difference in the magnitude of the effect of protected areas on population trends between narrowly- and widely-distributed species.

We only examined overlaps with existing distributions, and we made no attempt to identify how much of the original or potential future distribution of threatened species must be restored and/or protected to ensure recovery and long term persistence, particularly in the context of global climate change and the shifts in distributions already observed (Parmesan 2006). We also restricted analysis to gross percentage overlap, without regard to spatial configuration of the protected area system. Not all fractions of a species distribution are expected to have equivalent value for population viability. For example, 62% of 4,239 threatened species worldwide are believed to be dependent on conservation at multiple sites (Boyd et al. 2008).

Any beneficial effect of protected areas on threatened species is likely to require ongoing investments in abatement of pervasive threats which occur in protected areas, despite the change in land-use represented by protected areas: particularly unnatural fire patterns, exotic plants, animals and pathogens, and visitors. Even low levels of visitor presence can have a significant impact on large carnivore behaviour (Reed and Merenlender 2008) and we know little about visitor impacts on other groups globally. Amphibians are undergoing a global decline, even in pristine forests inside protected areas, believed to be due to chytrid fungus attack and a warming climate (Whitfield et al. 2006). Mammal populations are declining in national parks in northern Australia (Woinarski et al. 2001) and also in African national parks (Craigie et al. 2010) for reasons that remain unclear. The effectiveness or otherwise of the management of Australian protected areas could not be evaluated with the available data in this study, and represents a key issue for further research.

Perhaps the single greatest benefit of protected areas is in preventing complete habitat loss. However, rates of expansion of protected areas may be too slow to counter widespread habitat destruction (McDonald-Madden et al. 2009). Habitat protection legislation is potentially much more powerful in stopping or slowing habitat destruction because it can be applied over all tenures and land-uses over an entire jurisdiction. Those states with the lowest proportions of species increasing or stable were also those with the highest land clearing rates at the time of the Assessment. Queensland (0.49% of the state's area cleared per annum), NSW (0.16%) and Tasmania (0.26%) all had rates of clearing an order of magnitude higher than clearing rates in other jurisdictions in 2001 (Hamblin 2001).

Overlap with other protected areas in IUCN classes V and VI did not show any correlation with increasing or stable trends, a result perhaps unsurprising due to the lesser strength of protection in such protected areas. In Australia and in many other countries, IUCN class V and VI protected areas may be logged, cleared, grazed by livestock and mined, begging the question if these "protected areas" have genuinely changed land-use (Taylor et al. 2009; Dudley 2008). Mammals are less diverse and abundant in forest reserves open to hunting than on national parks closed to hunting in Costa Rica (Carrillo et al. 2000). More systematic field measurement of threatened species population trends on protected areas of different types is needed to assess the comparative effectiveness of investments in these different types of protected areas, which are increasingly favored due to their lower cost (Sattler and Taylor 2008).

The observed negative correlation of upward and stable species trends with numbers of conservation-oriented natural resource management actions does not necessarily mean that such activities have perverse, harmful effects on threatened species. Indeed, it is much more likely the direction of causation is reversed, with natural resource management activity being targeted to landscapes already highly modified by agriculture and as a consequence, in places where threatened species are mostly in decline. Indeed we found that numbers of such activities were negatively correlated with the proportion of natural vegetation remaining in subregions, supporting just such a differential targeting explanation (results not shown).

The absence of any significant relationship between numbers of recovery actions applied to subregional populations of species and the associated trends that we document here might be explained in a number of ways: recovery actions have not had time to produce an outcome; actions have not actually been implemented; or actions have been implemented but are ineffective. Either way, this result is surprising considering that species with dedicated recovery plans (the basis for recovery actions) in the United States are more likely to be increasing and less likely declining than species lacking plans (Taylor et al. 2005). Too few species in Australia had formal recovery plans at the time of the Assessment to permit a similar such analysis here. More importantly, we lack sufficient data on timing and degree of implementation of recovery actions or natural resource conservation actions to be able to distinguish among the foregoing hypotheses.

The scale of the benefit of protected areas suggested by these results was still limited compared with the pervasive pattern of decline of threatened species. The proportion of threatened species mostly or entirely in decline is alarmingly high, suggesting a need for greatly increased investments in strict protection of habitats and abatement of pervasive threats. Of all conservation activities, only expansion of strictly protected areas and possibly also legislation to control habitat loss, are associated with stabilization or recovery of threatened species in Australia.

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