Protected areas as biodiversity benchmarks for human impact: agriculture and the Serengeti avifauna

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Protected areas as biodiversity benchmarks allow a separation of the direct effects of human impact on biodiversity loss from those of other environmental changes. We illustrate the use of ecological baselines with a case from the Serengeti ecosystem, Tanzania. We document a substantial but previously unnoted loss of bird diversity in agriculture detected by reference to the immediately adjacent native vegetation in Serengeti. The abundance of species found in agriculture was only 28% of that for the same species in native savannah. Insectivorous species feeding in the grass layer or in trees were the most reduced. Some 50% of both insectivorous and granivorous species were not recorded in agriculture, with ground-feeding and tree species most affected. Grass-layer insect abundance and diversity was much reduced in agriculture, consistent with the loss of insectivorous birds. These results indicate that many species of birds will become confined to protected areas over time. We need to determine whether existing protected areas are sufficiently large to maintain viable populations of insectivorous birds likely to become confined to them. This study highlights the essential nature of baseline areas for assessing causes of change in human-dominated systems and for developing innovative strategies to restore biodiversity.

Keywords: protected areas; ecological baselines; biodiversity; Serengeti; agriculture; development

1. INTRODUCTION

There is much scientific concern that the loss of living organisms will reduce the capacity of our ecosystems to provide important services (Ehrlich 1988; Walker 1992, 1995; Lawton & Brown 1993; Schulze & Mooney 1993; Kunin & Lawton 1996; Rapport *et al.* 1998; Chapin *et al.* 2000), or to counteract the effects of global climate change (Petchey *et al.* 1999). A particular concern is that the consequences of species extinction on ecosystems may not be detected until conditions deteriorate beyond our ability to reverse the loss. Some ecosystems respond to disturbances by losing few species at first and many later on, producing multiple states (Holling 1973, 1986; May 1977). Remedial measures are most likely to be effective during the period of initial slow change, if such change could be detected.

Change in species richness and abundance can be monitored over time in different habitats. However, such change by itself does not allow us to distinguish between long-term environmental trends and the more direct impacts of human exploitation. To distinguish these causes we need an ecological benchmark that acts as a baseline relatively free of human interference. Such baselines control for local environmental change while emphasizing the difference in human impact. Protected areas potentially provide a basic global network of reference sites (Arcese & Sinclair 1997; Sinclair 1998). Here,

we illustrate our approach by describing a previously unnoted but substantial loss of bird diversity that was only detected by reference to an ecological baseline, the Serengeti ecosystem. We also test if changes in the diversity and abundance in birds were related to changes in arthropod abundance as a consequence of land use and habitat type.

2. STUDY AREA AND METHODS

The Serengeti ecosystem (34–36° E, 1–4° S) in Tanzania, East Africa, has been protected as a national reserve or park since the 1920s. Similar natural savannah extended west of the present park borders covering about 2050 km² until agriculture, smallholdings with cereal and root crops, took over in the 1950s, and this now abuts the western border of the natural ecosystem (Sinclair 1979, 1995). We selected a similar area (1840 km²) of native savannah in northern Serengeti as the reference baseline immediately adjacent to the agricultural area. The present agricultural and savannah areas were originally similar in flora and fauna, geology, soil nutrients and other ecological features (White 1915; Percival 1924; Sinclair 1995). The predominant vegetation of the protected area in northern Serengeti is a savannah dominated by *Acacia* and *Terminalia* trees in tall (1 m) perennial grassland of *Hyparrhenia* and *Themeda* grass species. Agriculture, which forms an abrupt boundary with the savannah on the western border, has removed most trees. Many small native shrubs surround crops of millet and cassava.

During 1997–2002 we conducted nine censuses of the bird fauna in both savannah and agriculture using vehicle transects on either side of the savannah–agriculture boundary. Transects were 5 km long and spaced at least 5 km apart. There were 22

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savannah transects but only eight agriculture transects owing to lack of access roads. Transects were driven slowly (30–50 km h⁻¹), stopping where necessary using two observers and a recorder. All species, their number and habitat were recorded up to 50 m either side of the track. The bird groups counted were medium and large insect-eating species, and all seed- and fruit-eating species. These focal species were easily detectable in the open grassy habitats that we surveyed and visibility was similar in the two areas. These transects provided an index of density that allowed comparison of the agriculture and savannah areas using identical methods. For each transect we calculated the mean density index over all nine surveys and then estimated the variance between transects. Species diversity was calculated using rarefaction (Heck *et al.* 1975; Krebs 2000; Hughes *et al.* 2001). Rarefaction compares observed species numbers between habitats that have different sample sizes. A curve of species number against sample size of individuals counted was estimated from averaging randomizations of the observed accumulation curve using software described in Krebs (2000).

We also estimated the abundance of grass-living arthropods (flies, planthoppers, wasps and bees) using green pan traps (New 1998) as indicators of invertebrate food abundance. Insect abundance in the region varies markedly by season, with lows occurring in the dry season and highs in the rainy season (February–May). We counted the number per trap of distinct types (morphospecies) and abundance of individuals in each arthropod group from the trapping session of February 2000, the month of highest catch. There were two agricultural and two savannah sites. One savannah site was immediately adjacent to a treeless grassland site. Each site contained 6–15 replicate pan traps placed systematically in grass verges around fields in agricultural sites, and on a grid in typical savannah grass sites in the protected area. Abundance was measured as the number of each morphospecies per trap per day with the variance estimated between traps on a site.

3. RESULTS

(a) *Index of bird density*

We surveyed 39 species of insectivore and 28 seed or fruit feeders in the agricultural area, these being a subset of those found in the adjacent natural savannah. The mean density in agriculture over all surveys in the 5 years was compared with the mean density of the same species in the savannah area (table 1; figure 1). Over all species the density in agriculture was one-quarter of the density of the same species in savannah. Between areas there was a greater difference in insectivores than granivores. The abundance of tree feeders differed the most, those in agriculture being only 10% of savannah, and this affected both insectivores and seed or fruit feeders. Ground feeders also differed markedly with agricultural densities being some 30% of savannah densities. The insectivores accounted for most of this difference. Shrub feeders were the least affected (65% of savannah) and the difference in density was not significant at $p < 0.05$ because of the very small sample size. We see the same pattern of differences in feeding type and vegetation type when all species in savannah are compared with those in agriculture (table 1).

Table 1. The index of bird density (observations per km²) of insectivorous and seed or fruit feeders on 5 km transects in agriculture compared with the same species in adjacent native savannah (% agric/sav) in northern Serengeti, including only those species that occur in both habitats. (The 'all savanna species' columns refer to the comparison with all species in savannah (% agric/all spp.) regardless of whether they also occurred in agriculture. Probability calculated from *t*-tests.)

	agriculture			savannah			all savannah species				
	species <i>n</i>	density (<i>n</i> km ⁻²)	s.e.m.	density (<i>n</i> km ⁻²)	s.e.m.	<i>p</i>	% agric/sav	all sav. spp.	density (<i>n</i> km ⁻²)	s.e.m.	% agric/all spp.
all species	67	17.8	2.53	63.12	7.56	0.001	27.5	149.0	84.34	8.60	20.6
insectivores	39	10.44	2.25	45.86	6.54	0.010	22.8	92.0	60.05	6.79	17.4
seed/fruit feeders	28	6.93	0.87	17.26	2.72	0.050	40.1	57.0	24.2	3.18	28.5
ground, all species	36	7.3	1.4	22.70	3.45	0.010	32.2	73.0	31.44	4.22	23.2
ground insectivores	17	2.98	1.03	14.46	2.25	0.010	20.6	37.0	17.23	2.61	17.3
ground granivores	19	4.32	0.75	8.24	1.93	n.s.	52.4	36.0	14.21	2.39	30.4
shrub, all species	19	6.83	2.06	10.37	1.79	n.s.	65.9	32.0	12.7	1.96	53.8
shrub insectivores	11	5.24	2.27	8.01	1.68	n.s.	65.4	22.0	9.93	1.70	52.8
shrub seed/fruit feeders	6	1.59	0.78	2.36	0.88	n.s.	67.5	10.0	2.78	0.89	57.3
tree, all species	14	3.24	0.97	30.05	4.48	0.001	10.8	44.0	40.20	4.48	8.1
tree insectivores	11	2.23	0.82	23.39	4.20	0.001	9.5	33.0	32.89	4.48	6.8
tree seed/fruit feeders	3	1.02	0.73	6.67	0.79	0.010	15.3	11.0	7.30	0.79	14.0

Figure 1. Index of bird density per square kilometre estimated on 5 km transects in Serengeti savannah (open bar) and adjacent smallholding agricultural land (solid bar). (a) There was a fourfold decline in density in agriculture for insectivores and a threefold decline in seed and fruit feeders for the same species. (b) In terms of vegetation structure there was a 10-fold decline in tree dwellers, a threefold decline in ground dwellers but only a 40% decline in shrub dwellers. Vertical lines indicate one s.e.m.

(b) Bird species richness

The lower density of birds in agriculture meant that there were uneven sample sizes between agriculture and savannah with which to compare species richness (table 2). Rarefaction estimates, therefore, were used to calculate the probable number of species seen in savannah for the same sample size as that in agriculture (table 2). The cumulative rarefaction curve for all species showed that the number of species in agriculture was some 75% that for the same sample size in savannah. Moreover, the number in agriculture was approaching an asymptote (*ca.* 70–80 species) whereas the number in savannah continued to climb to 149 species. Thus, *ca.* 50% of the species drop out in agriculture. This pattern of species loss is similar for the subsets of insectivores, seed or fruit feeders, ground and tree feeders, and we illustrate this pattern for ground feeders (figure 2). Only in shrub feeders were there no significant differences in rarefaction estimates, but again this might have resulted from the small sample size.

Three main groups of species were affected by the transition from protected to agricultural area. These were: (i)

the large ground birds such as bustards (Otididae), game birds (Phasianidae) and sandgrouse (Pteroclididae); (ii) the small grass-layer insectivores that include the larks (Alaudidae), pipits (Montacillidae) and warblers (Sylviidae); and (iii) species that used trees for feeding (wood-hoopoes (Phoeniculidae), warblers), nesting (hornbills (Bucerotidae), starlings (Sturnidae)), or perching to ambush grass insects (shrikes (Laniidae), flycatchers (Muscicapidae)).

Over the nine surveys only three species (four individuals) of raptors were observed in agriculture compared with 15 species and 104 individuals in savannah.

(c) Insect abundance

All three groups of grass-layer insects (planthoppers, flies and wasps) were found to be both less abundant and less diverse in agricultural compared with protected savannah sites (figure 3*a,b*). In general, abundance in agriculture was 20–50% that in savannah. As with the birds the lower abundance resulted in a smaller sample of grass-layer insects in agriculture. Rarefaction analysis of morphospecies per trap for the whole February–May 2000 period showed that with the same sample size (350 individuals) there were 38 (s.d. = 1.3) types of grass-layer insects per trap in savannah and 27 (s.d. = 0.5) types in agriculture. Both groups had reached an asymptote indicating that there are *ca.* 30% more types in savannah. By contrast, the same insect groups in native grassland were similar both in abundance and diversity to those in savannah. Thus, insect abundance in the grass layer was greater in natural grassland than in agriculture (figure 3*a,b*). This indicates that the removal of trees in agricultural areas was not the cause of the difference in insect abundance, this difference being more likely a consequence of human disturbances to the grass layer itself.

4. DISCUSSION

The reduction in insectivorous bird diversity and abundance in agriculture, particularly among grass and tree-dwelling species, was coincident with a drop in the grass-layer arthropods that provide much of the food for this group. Many of the tree-dwelling species in our sample, such as the starlings and shrikes require trees for nesting or perching but feed in the grass layer. By contrast, the density of shrub-dwelling birds appeared to be less affected by agriculture, possibly because shrubs are abundant as field hedgerows. These agricultural communities never use insecticides so that lower abundance of grass-layer insects was not due to their use. Disturbance to the grass layer as a consequence of conversion to agriculture provides a more likely explanation for the arthropod decline. This decline is conservative because we measured only in the higher diversity grass verges and not in the crops. Thus, food supply is likely to be reduced in two ways: first by loss of area through conversion of grassland to crops and second by reduction within the remaining grassland.

The great reduction in insectivorous birds in agriculture would affect their ability to control insect pest outbreaks. Furthermore, the lack of raptors in agriculture, particularly the rodent specialists (e.g. black-shouldered kite (*Elanus caeruleus*), long-crested hawk eagle (*Spizaetus ayresii*)) that are abundant in savannah, may be the cause

Table 2. Observed numbers of insectivorous and seed- or fruit-feeding bird species and their sample sizes, and the rarefaction estimates of species number (and standard deviations (s.d.)) for the same sample sizes in agriculture and a similar area of native savannah in northern Serengeti.

	all species	insectivores	seed/fruit feeders	ground	shrub	tree
agriculture						
observed individuals	620	303	317	449	56	115
observed species	67	39	38	36	17	14
predicted individuals	600	300	300	400	50	100
predicted species	66.41	38.9	27.57	35.3	16.12	13.46
s.d.	0.74	0.31	0.63	0.79	0.82	0.68
savannah						
observed individuals	9205	5309	3896	4248	1178	3779
observed species	149	92	57	73	32	44
predicted individuals	600	300	300	400	50	100
predicted species	86.18	48.03	37.68	51.11	13.0	18.13
s.d.	4.06	3.14	2.55	2.72	1.87	2.07

Figure 2. Rarefaction curves for numbers of species of ground dwellers in native savannah (filled circles) and in adjacent agriculture (open circles). For the same sample of individuals (450) there were 30% fewer species in agriculture. The curve for agriculture is approaching an asymptote while the savannah curve climbed to 73 species. Vertical lines indicate one s.d.

of frequent outbreaks of rodents such as *Mastomys natalensis* reported for agriculture (Leirs *et al.* 1997). These ecosystem functions are now the focus of future work.

This study is an illustration of the use of protected areas as benchmarks for human induced change. It needs to be repeated in other protected areas. However, our findings raise several key points for those interested in monitoring the effects of humans on biodiversity. First, the decline in bird diversity and density that we observed is not one confined to technologically advanced agricultural systems, such as those in Europe (Krebs *et al.* 1999; Donald *et al.* 2001); we show that similar declines may also occur in traditional agricultural systems in the tropics. Moreover, we expect that further studies of the relationship between the intensity of agriculture and bird species diversity and abundance in Africa will corroborate the strong negative

Figure 3. Insects caught per pan trap per day in the wet season month of February 2000 in two savannah (open bars) and one matched grassland (grey bar) site in Serengeti National Park and two agricultural sites (black bars). Insects were identified as morphospecies: DIPT, flies; HOMO, planthoppers; WASP, wasps and bees. (a) The number of species declined in agriculture relative to savannah, but there was no difference between natural grassland and savannah. (b) The number of individuals per trap in each insect group declined in agriculture relative to savannah, but there was also no difference between grassland and savannah. Vertical lines indicate one s.e.m.

correlation between these variables reported recently in Europe (Donald *et al.* 2001). Second, despite the striking effect of agriculture on the bird fauna around Serengeti over the past several decades, this effect went unnoticed until we made the comparison with an adjacent protected area. Had this opportunity for comparison not existed, there would be no reliable means of evaluating the effect of agriculture on native bird communities in the region. Third, human dominated habitats are expanding rapidly throughout Africa and other tropical areas. In regions adjacent to Serengeti this expansion occurs at a rate of about 5% per year (Campbell & Hofer 1995), and much of the natural biota cannot coexist with humans (Sinclair & Arcese 1995). Our work indicates that several bird groups, particularly large ground nesters and tree feeders, will become increasingly confined to protected areas. Thus, we must ask if such areas in Africa and elsewhere are sufficiently large to maintain viable bird populations, among other species. Finally, these results point to an increasing need for community-based conservation (Getz *et al.* 1999). In the case of habitat conversion in the Serengeti region, many trees are cut for use in house construction and replanting often favours exotic species, particularly fast-growing Australian wattle and eucalypts. By replacing native with exotic species, many native insects, birds and other species are also likely to be dissuaded. Mitigating biodiversity loss by encouraging the planting of native tree, shrub and herbaceous species through education and monetary incentives may provide an alternative course of action (Sinclair *et al.* 2000).

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