

Rangeland degradation is poised to cause Africa's first recorded avian extinction

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Abstract

Rangeland degradation by livestock threatens several restricted-range species, but is largely overlooked by conservation biologists. The Sidamo lark *Heteromirafra sidamoensis*, confined to the Liben Plain grassland in southern Ethiopia, is critically endangered by bush encroachment, permanent settlement and agricultural conversion. Its global range was previously estimated at 760 km², but in 2007–2008 available habitat covered < 35 km². Density estimates from multi-model inference analysis of distance transect data provided a global population estimate of 90–256 adults (possibly with a serious sex-ratio bias towards males). Logistic regression models of habitat selection showed that males preferentially occurred in areas of grassland with greater cover of medium-length grass (5–15 cm), less cover of bare ground and fewer bushes. Habitat transects extending outward from its core range revealed massive and rapid bush encroachment, corroborating information from semi-structured interviews. The survival of both local Borana pastoralism and this species – mainland Africa's likeliest first avian extinction – depends on restoring seasonal patterns of grazing, resisting agricultural conversion of grasslands, reversing fire suppression policies and clearing bush.

Introduction

Rangeland degradation is causing major ecological transformation of savanna ecosystems grazed by livestock (see also van Vegten, 1983; Roques, O'Connor & Watkinson, 2001). Although consequent bush encroachment is considered a serious issue for the livelihoods of pastoralists (Oba, Stenseth & Lusigi, 2000; Angassa & Oba, 2008), the issue of rangeland degradation has received surprisingly little attention from conservation biologists. Despite this, a number of globally threatened species are solely dependent on savanna grasslands and shrublands with a long history of use by traditional pastoralist communities, for example great Indian bustard *Ardeotis nigriceps* (India and Pakistan), Sidamo lark *Heteromirafra sidamoensis* (Ethiopia) and Sharpe's longclaw *Macronyx sharpei* (Kenya) (BirdLife International, 2004).

Bush encroachment is affecting savanna grasslands in many regions of the world (Scholes & Archer, 1997; Roques *et al.*, 2001). Excessive grazing, changing browsing regimes, fire suppression and increasing levels of atmospheric carbon dioxide are all blamed, although their relative importance

remains unclear (Walker *et al.*, 1981; Scholes & Archer, 1997; Ward, 2005; Morgan *et al.*, 2007; Riginos & Young, 2007). Recommendations for improved management include scrub removal (Scholes & Archer, 1997; Angassa, 2002), livestock reduction and fire restoration (Roques *et al.*, 2001; Angassa & Oba, 2008), and tolerance of wild ungulate assemblages (Augustine & McNaughton, 2004). While the benefits of rangeland management for livestock production are well understood (e.g. Angassa & Beyene, 2003; Angassa, 2005; Dalle, Maass & Isselstein, 2006), the impacts of both encroachment and management on associated wild fauna are not, despite evidence that savannas have long ecological continuity over evolutionary timescales (Bond, Midgley & Woodward, 2003).

Until recently the rangelands of southern Ethiopia were among the most productive pastures in Africa (Angassa, 2002). The region includes the arid savannas and grasslands of the Borana plateau (95 000 km²), an Endemic Bird Area (EBA 114, South Ethiopian highlands: Stattersfield *et al.*, 1998) to which six globally threatened bird species are restricted (BirdLife International, 2004). Three among them (Sidamo lark, Ethiopian bush-crow *Zavattariornis*

stresemanni and White-tailed swallow *Hirundo megaensis*) are nowadays confined to pastoralism-dependent savanna and grassland. Pastoralism is the EBA's predominant land use, historically managed by the traditional Borana system that included complex patterns of transhumance, seasonal use of wet- and dry-season ranges, and burning to control scrub (reviewed by Coppock, 1994; Oba & Kotile, 2001). In recent decades, increasing human and livestock populations, disruption of traditional management and agricultural conversion of communal pastures have caused widespread rangeland degradation (reviewed by Coppock, 1994; EWNHS, 2001; Desta & Coppock, 2002; Angassa & Beyene, 2003; Tefera, Snyman & Smit, 2007). In particular, bush encroachment has steadily increased, reducing herbaceous production and grass cover and undermining pastoralist livelihoods (Oba *et al.*, 2000; Dalle *et al.*, 2006).

The most range-restricted bird species of the South Ethiopian highlands EBA is the poorly known Sidamo lark, so far as is known confined entirely to a small plateau with a core of grassland known as the Liben Plain, and thus especially vulnerable to rangeland transformation (EWNHS, 2001; Collar *et al.*, 2008). In this study we (1) estimate the species's current range size and population density, deriving a population estimate; (2) analyse its habitat preferences; (3) investigate habitat changes within its range; (4) recommend landscape-scale interventions to prevent its extinction.

Materials and methods

Study site

The Liben Plain, centred around 5°15'N 39°43'E, is situated in the Guji Zone of southern Ethiopia, 430 km SSE of Addis Ababa and 12 km ESE of Negele (Fig. 1); satellite imagery (Google Earth, date unknown) shows a well-defined plateau with no other similar vegetation within at least 200 km. The region is semi-arid: mean annual rainfall at Negele was 761 mm during 1965–2002, with high inter-annual variation, but declining by 119 mm per decade since the early 1980s (Seleshi & Zanke, 2004). The main rainfall season is March–May (373 mm in 2002), and secondarily in October–December (Seleshi & Zanke, 2004).

The Liben Plain consists of a shallow, internally draining basin on limestone sediments (Gaggi, 2002) between the Genale and Dawa Rivers, at 1500–1630 m a.s.l. Its grassland is surrounded by dense *Acacia-Commiphora* thicket and, to the north-west, intensive cultivation. Its central drainage tract is also cultivated with maize, beans and cereals, mainly near a large pond considered of natural origin (Gaggi, 2002) (Fig. 1). The grass sward is typically <0.5 m high and thinly scattered with small trees, including *Acacia seyal*, and low thorny and herbaceous shrubs including *Acacia drepanolobium* and *Solanum tettense*; the former is considered symptomatic of chronically overgrazed rangeland (Tefera *et al.*, 2007). There are several dense stands of giant fennel *Ferrula communis*, a species associated with heavily grazed areas

(Puff & Nemomissa, 2005), and a high density of circular bare-ground nests (diameter 2.7–6.4 m; mean 4.5 m, $n = 25$) of harvester ants *Messor cephalotes*.

Sidamo lark density

In June 2007, Sidamo larks were censused along 12 distance transects, totalling 60 km (Fig. 1). Transects were walked at $c. 5 \text{ km h}^{-1}$ by teams of two (once 1, once 3) people, with regular stops to record habitat. Transects were positioned a minimum 1 km apart for independence; the maximum perpendicular distance at which we detected lark song was 444 m (typically <300 m). GPS coordinates were taken of each lark's position when first sighted (black circles in Fig. 1), and its perpendicular distance to the transect line measured by GPS to 1 m accuracy. Only larks detected on transects were included in analyses. Larks were most often detected by their song or occasionally call (see Collar *et al.*, 2008), and rarely when running along the ground. Transects started at $c. 06:30$ (range 06:20–06:50), about 30 min after first light, and ended at or before 10:30. Lark vocalizations tended to diminish towards mid-morning, although in favourable conditions (little wind, moderate temperatures) sometimes continued past 11:00. Transect data from outside the observed species's range (see Fig. 1) were excluded when estimating density, but data from all transects were used to model male habitat selection.

Sidamo lark habitat preferences

In June 2007, vegetation and human land-use characteristics for the Liben Plain were estimated every 250 m along each transect (open circles in Fig. 1). Biases were minimized by rotating observers (who agreed estimates at each location) among survey teams. The following traits were recorded (1) within a radius of 25 m: number of trees, *M. cephalotes* ant nests, cattle trails and fennel plants; (2) in each of two circles of radius 5 m within the 25 m radius area, with mean values used in subsequent analyses: number of bushes (defined as woody shrubs of height <1.5 m) and cowpats, percentage cover of bare ground (including ant nests), and proportions of grass cover in height categories (*a*) <5 cm; (*b*) 5–15 cm; (*c*) 15–40 cm; (*d*) >40 cm. Grass cover in each category was converted to percentage overall cover by multiplying by 1 minus proportion of bare ground.

As expected, ground-cover variables (bare ground, grass length) were intercorrelated. Cover of medium-length grass (*b*, 5–15 cm) was moderately negatively correlated with both cover of shortest-length grass (*a*: $R^2 = 0.30$) and bare ground ($R^2 = 0.34$), and weakly positively related to cover of longer grass categories (*c* and *d*: $R^2 = 0.21$ and 0.12, respectively). Other correlations among cover variables were weak, with bare ground weakly negatively correlated with grass-length categories *a*, *c* and *d* (R^2 ranging from 0.04 to 0.19), the two longer grass-length categories (*c* and *d*) weakly positively correlated with each other ($R^2 = 0.23$), and negatively related to cover of the shortest grass-length category *a* ($R^2 = 0.20$ and 0.14 respectively). Such

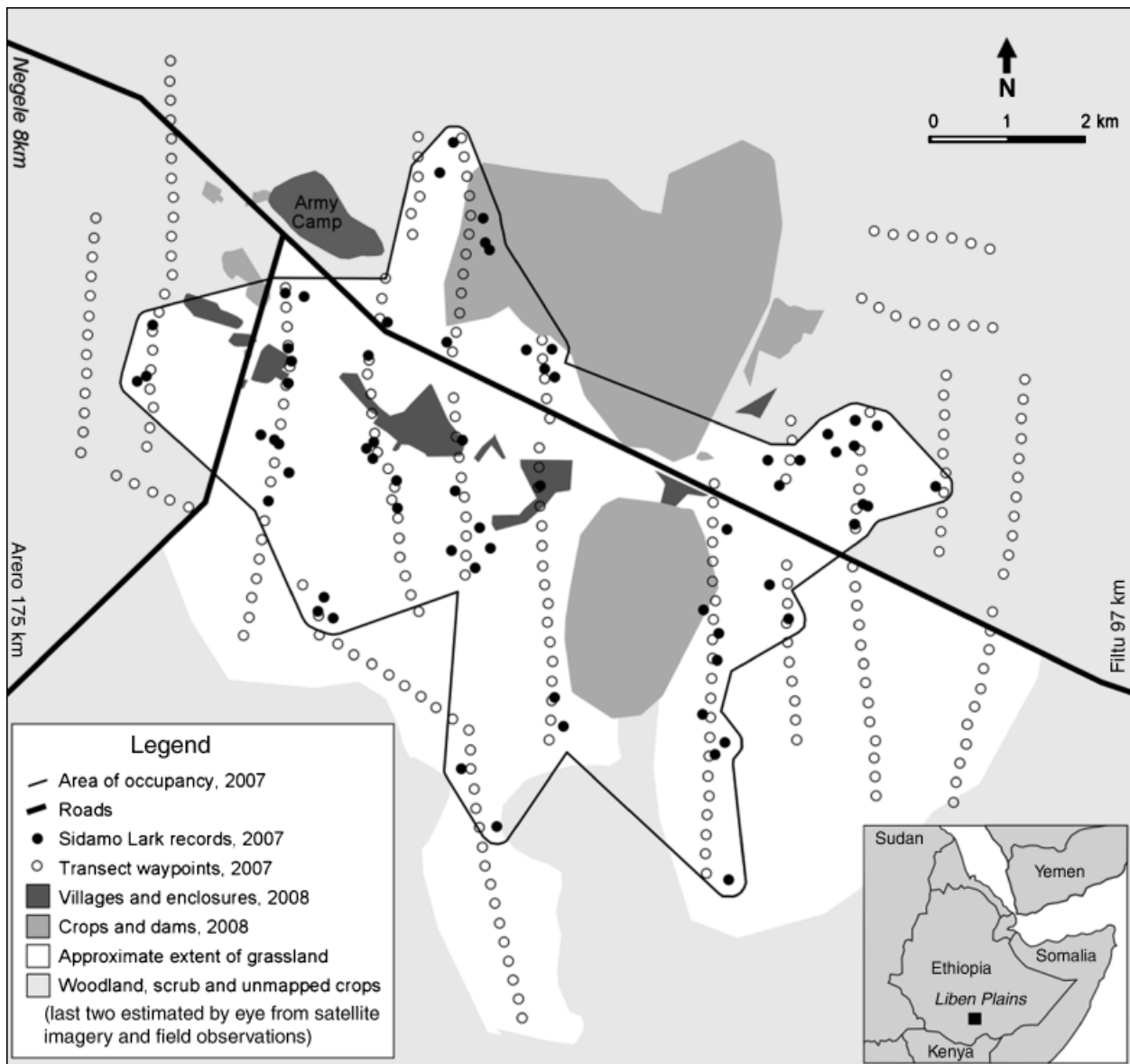


Figure 1 Map of the Liben Plain, showing Sidamo lark *Heteromirafrā sidamoensis* records, line transects, habitat types and the estimated world range of the species (enclosed within line; see 'Materials and methods' for details). *Note:* The apparent presence of larks in cultivations owes to these having expanded in extent between 2007 (when larks were surveyed) and 2008 (when crop fields were mapped). Sidamo larks were only recorded in grassland, never in crops.

moderately correlated variables may still be included as independent predictors in multivariate analyses (tolerance > 0.10: Quinn & Keough, 2002) and we therefore began by constructing minimal models by backward elimination from a full model incorporating all the original cover variables.

Bush encroachment and rangeland degradation

In June 2008, we assessed bush encroachment using two approaches, (1) quantitative vegetation transects; (2) qualitative semi-structured interviews with resident pastoralists. The density

and height of woody vegetation were sampled along six transects, selected using GIS, extending through the peripheral ecotones of the plain to the north-east, south-east, south-west, west and north, while avoiding areas of cultivation. Each transect started within the lark's range, headed perpendicular to the range boundary and extended 6–7 km outside it. Every 200 m the density of woody vegetation (trees and saplings with stem circumference > 5 cm) was assessed by the point-centred quarter method (Cottam & Curtis, 1956); height of tallest tree within 50 m and identity of closest tree or sapling were also recorded. Point-to-plant distances were measured by laser rangefinder and transects followed using GPS. A 2-h interview

(18 June 2008) with members of the Elders Committee of Siminto Peasant Association, that includes half the Liben Plain, consisted of questions and answers (translated by local government officials) concerning the conditions of the plain when the elders were young, and their explanations of subsequent changes.

Analyses

Range size was estimated in two ways, the second more precautionary: (1) a most probable estimate, defined by a polygon of the external point locations where larks were recorded, plus a buffer of the effective strip width (ESW; Thomas *et al.*, 2006) as generated during the distance sampling analyses, excluding those areas of cultivation and army camp buildings within this polygon (see Fig. 1); (2) a conservative estimate, defined as above but without any buffer. Areas of unsuitable habitat (cultivations and army camp) were mapped by GPS while walking perimeters. Cropland had increased in extent between 2007 (when larks were surveyed) and 2008 (when crops were mapped) (see Fig. 1). Areas were calculated using ArcGIS 9.1 and the Behrmann Equal Area Projection (ESRI, 1999–2004).

We used only records of territorially singing males for density estimation. Using Distance 5.0 (Thomas *et al.*, 2006), we explored different key functions (uniform, half normal, negative exponential and hazard rate) and adjustment terms (none, cosine, hermite and simple polynomials), both without truncation and with truncation discarding the most distal 5% of observations (Buckland *et al.*, 2001). For each key function, the adjustment term providing the lowest Akaike's Information Criterion (AIC) was selected. A model-averaged estimate of density and its unconditional sampling variance was calculated using the Akaike weight and conditional sampling variance of each model (Burnham & Anderson, 2002).

The software GeoDa 0.9.5i (Anselin, 2003) was used to estimate spatial autocorrelation of habitat variables. This was calculated as Moran's I , which varies from -1 to 1 , reflecting negative and positive spatial autocorrelation, respectively (Fortin & Dale, 2005). Corresponding P -values were generated by randomization with 999 replicates. Habitat preference was modelled using logistic linear models (with binomial errors and a log link function) implemented in R (R Development Core Team, 2006); selection of final models through backward elimination was based on changes in AIC. Correlations between predictors used arcsine square-root-transformed proportions of bare ground and grass cover, but

these were left untransformed in the logistic models, as transformation resulted in models with lower AICs. Data on tree density were analysed using linear mixed-effects models, with distance from lark range edge as an independent variable, and transect identity as a random factor. Tree density and height were log-transformed before analysis.

Results

Spatial structure and human impact on the Liben Plain

Habitat variables were recorded at 320 locations, of which 252 were random locations along the transect lines and 68 were locations where larks were recorded. Most habitat variables were only weakly positively spatially autocorrelated (Moran's $I < 0.30$), except fennel density (Moran's $I = 0.717$), path density (Moran's $I = 0.585$) and grass length cover (Moran's $I = 0.631, 0.495, 0.342$ and 0.358 , respectively).

Signs of cattle use (paths or cowpats) were present in 96% of the 252 random point locations on the Liben Plain. Both of these measures of grazing intensity were positively related to the extent of bare ground (Poisson GLMs, paths: $P < 0.001$; dung, $P < 0.001$), suggesting a likely causal relationship. By contrast, number of ant nests was unrelated to extent of bare ground (Poisson GLM, $P = 0.37$), suggesting that these can be considered causally independent predictors.

Geographical range, density and population size of the Sidamo lark

The most probable range size of the Sidamo lark (illustrated in Fig. 1 and including a buffer of 212 m, the ESW for the distance model with lowest AIC) was estimated to be 34.2 km^2 . A more conservative estimate, excluding the outer buffer around point locations, was 27.5 km^2 . Within this range 37 km of distance transect was walked, during which 69 Sidamo larks (two at one location), including 62 singing males, were recorded.

All models of density with 5% truncation of extreme distance values performed substantially better (AIC_c range 671–675) than those without truncation (AIC_c range 726–727); therefore we solely present results from truncated models. Models incorporating different functions describing decline in detectability with increasing distance from transect line gave similar results for ESW and estimated density (Table 1). The best fitting model (uniform, cosine

Table 1 Modelled density estimates of singing male Sidamo larks *Heteromirafra sidamoensis* under different detection functions, and model-averaged estimate of density calculated from Akaike weights (w_i) of individual models

Detection function, adjustment (order)	AIC _c	ΔAIC _c	w_i	ESW (effective strip width, m) ± SE	Density (singing males ha ⁻¹) ± SE
Uniform, cosine (1)	670.712	0.000	0.353	211.9 ± 25.9	0.0376 ± 0.0064
Negative exponential	671.239	0.527	0.271	192.1 ± 37.7	0.0415 ± 0.0095
Half-normal	671.308	0.596	0.262	225.0 ± 26.9	0.0354 ± 0.0059
Hazard rate	672.953	2.241	0.115	234.8 ± 34.5	0.0334 ± 0.0064
Averaged-model					0.0376 ± 0.0075

AIC, Akaike Information Criterion.

adjustment order 1, $AIC_c = 670.71$) provided a density estimate of 0.038 singing males per ha (95% CI, 0.027–0.053). However, two alternative models lay within just 0.6 AIC_c and a fourth within 10% of the AIC of this 'best model', supporting a model-averaging approach. The resulting mean estimate of density was 0.0376 ± 0.0075 SE. Extrapolating across the larger estimate of range, the number of singing males was 129 (95% CI: 78–179), and across the smaller estimate of range, 103 (95% CI: 63–144).

Habitat preferences of territorial males

During backward elimination of habitat variables based on transect data, neither area of bare ground nor cover of medium-length grass (*b*) were significant in the full model. However, the removal of one of these negatively related variables ($R^2 = 0.34$) rendered the other highly significant, indicating instability in model selection. We therefore present three alternative minimal models containing one or other of these variables, or the first principal component of the two combined (eigenvalue = 1.54, explaining 77% of their variation and loading positively on grass cover and negatively on bare ground, and not strongly spatially autocorrelated: Moran's $I = 0.298$). In all cases, model residuals were only weakly spatially autocorrelated (Moran's $I = 0.030, 0.027$ and 0.031 , respectively; all $P > 0.23$); thus, spatial autocorrelation is unlikely to be confounding.

Overall model performance was good (ca. 80% correct classification in all models: Table 2), although all models under-predicted presence. Biological interpretation of all three models was consistent (although AIC values provide greatest support for model 3): probability of lark presence is increased with greater cover of medium-length grass (5–15 cm), and decreased by greater area of bare ground.

Trees and bushes were consistently avoided and ant nests favoured in all models; in two models there was a weak pattern for avoidance of very short grass (< 5 cm) (Table 2). High densities of herbaceous fennel did not hamper lark incidence; 15% of records were at fennel densities of >40 plants per 25 m radius. However, Sidamo larks were never recorded from cultivated areas or dense stands of *A. drepanolobium* (medium grey shading in Fig. 1).

Agricultural and bush encroachment

The area of crops mapped within the core Liben Plain (numerous peripheral fields remained unmapped) in 2008 was 15.8 km². This represented a recent increase: several lark territories mapped in grassland in 2007 had in 2008 been converted to crops (Fig. 1).

Remnant open grassland was concentrated towards the middle of the plain, bordered by a variable-width ecotone into surrounding woodland or scrub. Density of woody vegetation increased beyond the range edge of the Sidamo lark (Fig. 2; slope \pm SE = 0.85 ± 0.05 , $F_{1,174} = 134.9$, $P < 0.001$). The principal plant species responsible were *A. seyal* (53% of nearest trees to points), *A. nilotica* (16%), *A. drepanolobium* (14%) and *Balanites aegyptiaca* (10%). Maximum height of woody plants also increased (Fig. 2; slope \pm SE = 0.34 ± 0.02 , $F_{1,169} = 203.2$, $P < 0.001$), indicating that trees nearer the lark's core range were younger and more recently established.

Elders interviewed confirmed this, reporting that (1) the plain was far more extensive 10–20 years ago; (2) four of the seven village clusters governed by their committee were formerly in grassland but are now in scrub; (3) grass formerly often reached breast height in places (in 2008 we qualitatively estimated that >90% of grass cover

Table 2 Alternative minimal models of habitat traits predicting Sidamo lark *Heteromirafra sidamoensis* incidence; model selection was based on changes in AIC

	Slope \pm SE	Z	P	Δ AIC
<i>Model 1</i> : AIC = 290.93 (overall 80.0%; absences 97.2%; presences 16.2%)				
Tree density	-0.96 \pm 0.51	-1.87	0.062	3.49
Ant nest density	0.28 \pm 0.15	1.86	0.062	1.46
Bush density	-2.13 \pm 0.84	-2.56	0.011	10.22
Grass cover <i>a</i> (0–5 cm)	2.72 \pm 1.19	2.30	0.022	3.60
Grass cover <i>b</i> (5–15 cm)	6.17 \pm 1.30	4.74	<0.001	24.90
<i>Model 2</i> : AIC = 293.32 (overall 79.7%; absences 97.2%; presences 14.7%)				
Tree density	-1.19 \pm 0.50	-2.27	0.023	6.20
Ant nest density	0.30 \pm 0.15	1.99	0.047	1.92
Bush density	-2.04 \pm 0.82	-2.49	0.013	9.78
Grass cover <i>a</i> (0–5 cm)	-1.64 \pm 0.85	-1.93	0.054	1.80
Bare ground	-5.06 \pm 1.15	-4.38	<0.001	22.52
<i>Model 3</i> : AIC = 288.54 (overall 79.7%; absences 96.8%; presences 16.2%)				
Tree density	-1.08 \pm 0.52	-2.08	0.038	4.74
Ant nest density	0.31 \pm 0.15	2.08	0.037	2.32
Bush density	-2.13 \pm 0.84	-2.55	0.011	10.19
PC of bare ground and grass cover <i>b</i> (5–15 cm)	0.65 \pm 0.13	4.94	<0.001	26.31

Percentages of absences, presences and overall records correctly classified by each model are reported alongside AICs. AIC, Akaike Information Criterion.

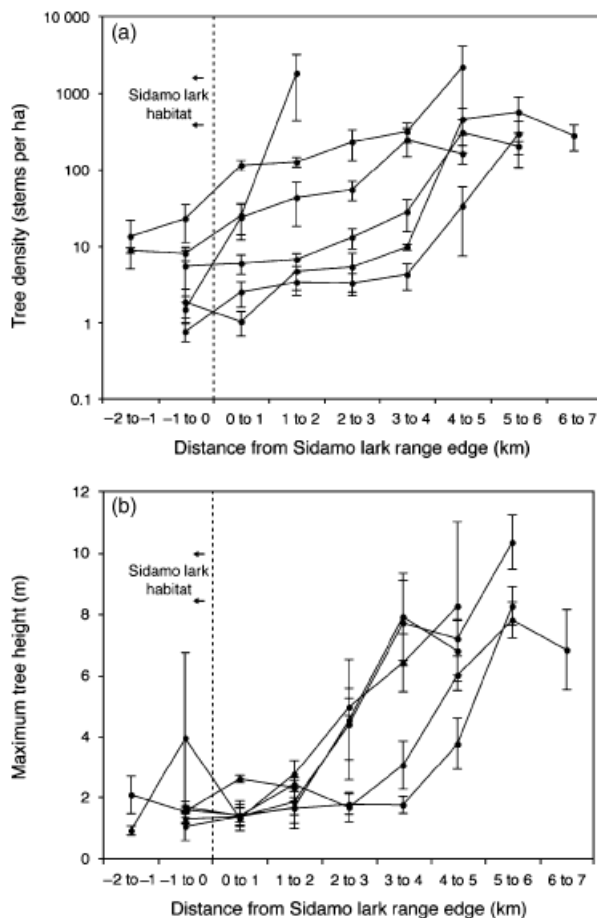


Figure 2 Density (a) and maximum height (b) of woody vegetation along six linear transects radiating out from the edge of the Sidamo lark's *Heteromirafra sidamoensis* range. Data points show means (\pm SE) of five point estimates within each 1 km distance band.

was < 5 cm); (4) milk yields had fallen over 98% from 20 to 0.35 L per cow over the past two to three decades; (5) increasing numbers of pastoralists were hence reluctantly turning to agriculture as an alternative means of subsistence.

Discussion

Threat status of the Sidamo lark

Prior to this study, the Sidamo lark's population size estimated by BirdLife International (2008) of 1600–2000 mature individuals represented an informed guess based on a breeding range estimate of 760 km² and extrapolation from breeding densities of 0.6 pairs ha⁻¹ of the congeneric Rudd's lark *Heteromirafra ruddi* in South Africa. In reality, the world range of the Sidamo lark appears to be a single grassland patch just 30–36 km² in area, and its density to be an order of magnitude lower, with a total adult male population of only 63–179. If an equal adult sex ratio is assumed, this suggests a similar number of females. However, threatened range-restricted bird species commonly

have strongly male-biased sex ratios (Donald, 2007), as do larks in general, possibly as a result of predation of incubating and brooding females (de Juana, Suárez & Ryan, 2004). We witnessed the predation of a presumed female brooding its young at night, suggesting that ever-sparsier cover may increase adult female mortality (Collar *et al.*, 2008). Using the average sex ratio for Critically Endangered species (0.7: Donald, 2007) suggests a total population size of 90–256. However, even the lower value might be optimistic, given that grassland condition has further deteriorated subsequent to density estimation.

Conversely, population size might have been underestimated if a key assumption of distance sampling methodology, that all males close to the transect line were detected, was not met. We consider this unlikely because physically disturbing birds typically stimulated them to sing (as in certain other lark species), but cannot exclude the possibility that singing responses are seasonal and that some males had ceased to sing by the time of our survey (some nests were found during June 2007 and June 2008: Collar *et al.*, 2008). By comparison, in October 2006 a record of seven singing males in one area of *c.* 0.28 km² of seemingly prime habitat suggested that local densities can be considerably higher (Collar *et al.*, 2008). Nonetheless, it seems unlikely that the total population size can be much in excess of 250 individuals.

Given these findings we recommend the species be uplisted to IUCN threat category Critically Endangered, using the following criteria (IUCN SSC, 2000): B1, extent of occurrence estimated to be < 100 km², and estimates indicating (1) existence at a single location and (2) continuing decline inferred and projected in: (1) extent of occurrence; (3) area, extent and/or quality of habitat; (5) number of mature individuals. Mainland Africa has yet to experience the extinction of a bird species (Butchart, Stattersfield & Brooks, 2006), but the rate of habitat loss and the tiny remaining range of the Sidamo lark strongly suggest it will very soon die out without urgent, concerted intervention.

Threats and conservation recommendations

Sidamo larks avoided woody vegetation, very short grass and bare ground, all symptomatic of degraded rangelands, and favoured a grass sward of intermediate height (5–15 cm). They were never recorded from croplands. Rangeland degradation and agricultural conversion are the clearest threats to the persistence of the Sidamo lark. Field transects, interviews with stakeholders and local informants and previous reports (Wondafrash, 2005; Borghesio, unpubl. data, 2006) all suggest that the area of open grassland suitable for Sidamo larks has rapidly diminished in extent owing to bush encroachment, erosion and crop planting, and has changed in structure.

This reflects similar changes over much of the South Ethiopian highlands EBA, where bush cover has increased by some 50% in recent decades (Coppock, 1994; Dalle *et al.*, 2006). Borana pastoralists attribute bush encroachment to a government ban on rangeland burning and to more frequent

droughts, and ascribe overgrazing to a weakening of traditional range and water management strategies that previously regulated grazing patterns (Angassa & Beyene, 2003; Dalle *et al.*, 2006; Angassa & Oba, 2008, this study). The traditional 'Geda' system involved seasonal movement of cattle in a socially regulated commons, but has been eroded by transition to year-round grazing, crop farming and permanent settlement (Coppock, 1994; Angassa & Oba, 2008). In interviews, elders reported that on the Liben Plain the breakdown of the Geda system has been exacerbated by unregulated grazing by armed Somali nomads. Elsewhere in southern Ethiopia, pond-building has promoted local overgrazing (Angassa & Beyene, 2003; Tefera *et al.*, 2007), and this probably explains the conspicuous erosion and encroachment in the eastern half of the Liben Plain (Collar *et al.*, 2008). Thus all evidence suggests that a breakdown in traditional transhumance is primarily responsible for grassland degradation on the Liben Plain, increasing livestock densities far beyond the intermediate levels that could maintain suitable Sidamo lark habitat. In turn this has encouraged pastoralists to convert grassland to crop-fields, in which the Sidamo lark does not occur at all. Such conversion is carried out by a small number of individuals, reducing access to grassland resources by the wider community, placing further pressure on both the sustainability of grazing and pastoral livelihoods (see also Angassa & Oba, 2008).

What mitigation might be practical to benefit both the Sidamo lark and Borana inhabitants? Possible measures include: (1) institutional reinvigoration of traditional range and water management strategies (Angassa & Beyene, 2003; Dalle *et al.*, 2006; Angassa & Oba, 2008, but see Watson, 2003 for cautions), aiming to establish sustainable stocking densities; (2) reversal of agricultural expansion by making pastoralism once more sustainable; (3) resumption of burning to control scrub, using experimental blocks as pilots; (4) clearance of encroaching bush. This last has already been extensively studied on the Borana plateau: *A. drepanolobium* in particular requires a combination of fire, mechanical clearance and chemical application (Coppock, 1994). Clearance in the Yabelo area has resulted in improvements in range condition, as reflected by grass cover and soil condition (Angassa, 2002), although larger-scale bush clearing attempts by development agencies there have had negligible impact (Gemedo Dalle *et al.*, 2006). Experimental work on the Liben Plain is urgently needed. Other threats to the Sidamo lark are beyond the scope of local conservation intervention: notably, conflict in Somalia (generating grazing incursions by armed nomads), increased frequency of drought (exacerbating the impacts of overgrazing), and possibly rising atmospheric levels of carbon dioxide (favouring growth of bush over grass).

Rangeland degradation as a conservation issue

The needs of the Sidamo lark appear to coincide with those of local Borana pastoralists, who identified deteriorating

pasture quality as their most critical problem. From the latter's perspective, increased woody plant cover decreases livestock forage, causes difficulties for herding livestock, shelters harmful wildlife and prevents access to available grass (Angassa & Beyene, 2003; Dalle *et al.*, 2006). Diminished grazing resources have helped transform the Borana region from one of Africa's richest rangeland areas to an area fraught with famine and ethnic clashes (Coppock, 1994). From a conservation perspective, rangeland degradation is an insidious and relatively unspectacular form of anthropogenic habitat transformation that has received relatively little attention. This study demonstrates that it may soon cause Africa's first modern bird extinction, while elsewhere in southern Ethiopia bush encroachment has recently been identified as a threat to the endemic Ethiopian bush-crow (Borghesio & Giannetti, 2005) and perhaps white-tailed swallow (Mellanby *et al.*, 2008). Thus a problem whose social dimensions have preoccupied numerous agroscientists and development agencies may also have ramifications for unique wildlife assemblages. Certainly in southern Ethiopia intervention is urgently needed to assure the persistence of both local livelihoods and key biodiversity.

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References

- Angassa, A. (2002). The effect of clearing bushes and shrubs on range condition in Borana, Ethiopia. *Trop. Grass.* **36**, 69–76.
- Angassa, A. (2005). The ecological impact of bush encroachment on the yield of grasses in Borana rangeland ecosystem. *Afr. J. Ecol.* **43**, 14–20.
- Angassa, A. & Beyene, F. (2003). Current range condition in southern Ethiopia in relation to traditional management strategies: the perceptions of Borana pastoralists. *Trop. Grass.* **37**, 53–59.
- Angassa, A. & Oba, G. (2008). Herder perceptions on impacts of range enclosures, crop farming, fire ban and bush encroachment on the rangelands of Borana, southern Ethiopia. *Hum. Ecol.* **36**, 201–215.

- Anselin, L. (2003). *GeoDa 0.9 User's Guide*. Urbana-Champaign, IL: Spatial Analysis Laboratory, University of Illinois.
- Augustine, D.J. & McNaughton, S.J. (2004). Regulation of shrub dynamics by native browsing ungulates on East African rangeland. *J. Appl. Ecol.* **41**, 45–58.
- BirdLife International. (2004). *Threatened Birds of the World 2004. CD-ROM*. Cambridge, UK: BirdLife International.
- Bond, W.J., Midgley, G.F. & Woodward, F.I. (2003). The importance of low atmospheric CO₂ and fire in promoting the spread of grasslands and savannas. *Global Change Biol.* **9**, 973–982.
- Borghesio, L. & Giannetti, F. (2005). Habitat degradation threatens the survival of the Ethiopian bush crow *Zavattariornis stresemanni*. *Oryx* **39**, 44–49.
- Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. & Thomas, L. (2001). *Introduction to distance sampling: estimating abundance of biological populations*. Oxford: Oxford University Press.
- Burnham, K.P. & Anderson, D.R. (2002). *Model selection and multimodel inference: a practical information-theoretic approach*. New York: Springer-Verlag.
- Butchart, S.H.M., Stattersfield, A.J. & Brooks, T.M. (2006). Going or gone: defining 'Possibly Extinct' species to give a truer picture of recent extinctions. *Bull. Brit. Orn. Club* **126A**, 7–24.
- Collar, N.J., Dellelegn Abebe, Y., Fishpool, L.D.C., Gabremichael, M.N., Spottiswoode, C.N. & Wondafrash, M. (2008). Type locality, behaviour, voice, nest, eggs and plight of the Sidamo Lark *Heteromirafr sidamoensis*. *Bull. Afr. Bird Club* **15**, 180–190.
- Coppock, D.L. (1994). *The Borana plateau of southern Ethiopia: synthesis of pastoral research, development and change, 1980–91*. Addis Ababa: International Livestock Centre for Africa.
- Cottam, G. & Curtis, J.T. (1956). The use of distance measures in phytosociological sampling. *Ecology* **37**, 451–460.
- Dalle, Maass, B.L. & Isselstein, J. (2006). Encroachment of woody plants and its impact on pastoral livestock production in the Borana lowlands, southern Oromia, Ethiopia. *Afr. J. Ecol.* **44**, 237–246.
- Desta S. & Coppock, D.L. (2002). Cattle population dynamics in the southern Ethiopian rangelands, 1980–97. *J. Range Mgmt.* **55**, 439–451.
- Donald, P.F. (2007). Adult sex ratios in wild bird populations. *Ibis* **149**, 671–692.
- ESRI. (1999–2004). *ArcGIS: Release 9.0 [software]*. Redlands, CA: Environmental Systems Research Institute.
- EWNHS. (2001). Ethiopia. In *Important Bird Areas in Africa and associated islands: priority sites for conservation*: 291–336. Fishpool, L.D.C. & Evans, M.I. (Eds). Newbury & Cambridge, UK: Pisces Publications & BirdLife International.
- Fortin, M.-J. & Dale (2005). *Spatial analysis: a guide for ecologists*. Cambridge: Cambridge University Press.
- Gaggi, F. (2002). *Geological–hydrogeological survey report, Negele and Filtu Districts*. Addis Ababa: Cooperazione Internazionale (COOPI).
- IUCN SSC. (2000). *IUCN red list categories and criteria Version 3.1*. Gland, Switzerland: IUCN.
- de Juana, E., Suárez, F. & Ryan, P.G. (2004). Family Alaudidae (larks): family introduction. In *Handbook of the birds of the World*: 496–541. Vol. 9. del Hoyo, J., Elliott, A. & Christie, D.A. (Eds). Barcelona: Lynx Edicions.
- Mellanby, R.J., Ross, B., Watt, A., Wondafrash, M., Ewnetu, M., Broadhurst, C., Critchlow, R., Dadesa, A., Deas, T., Enawgaw, C., Gebremedhin, B., Graham, E., Maclean, S., McKean, M., Collar, N.J. & Spottiswoode, C.N. (2008). Distribution, abundance and habitat preferences of white-tailed swallow *Hirundo megaensis* and Ethiopian bush-crow *Zavattariornis stresemanni*, two southern Ethiopian endemics. *Bird Conserv. Int.* **18**, 395–412.
- Morgan, J.A., Milchunas, D.G., LeCain, D.R., West, M. & Mosier, A.R. (2007). Carbon dioxide enrichment alters plant community structure and accelerates shrub growth in the shortgrass steppe. *Proc. Natl. Acad. Sci. USA* **104**, 14724–14729.
- Oba, G. & Kotile, D.G. (2001). Assessments of landscape level degradation in southern Ethiopia: pastoralists versus ecologists. *Land Degrad. Dev.* **12**, 461–475.
- Oba, G., Stenseth, N.C. & Lusigi, W.J. (2000). New perspectives on sustainable grazing management in arid zones of sub-Saharan Africa. *Bioscience* **50**, 35–51.
- Puff, C. & Nemomissa, S. (2005). *Plants of the Simen*. Meise: National Botanic Garden of Belgium.
- Quinn, G.P. & Keough, M.J. (2002). *Experimental design and data analysis for biologists*. Cambridge: Cambridge University Press.
- R Development Core Team. (2006). *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.
- Riginos, C. & Young, T.P. (2007). Positive and negative effects of grass, cattle, and wild herbivores on *Acacia* saplings in an East African savanna. *Oecologia* **153**, 985–995.
- Roques, K.G., O'Connor, T.G. & Watkinson, A.R. (2001). Dynamics of shrub encroachment in an African savanna: relative influences of fire, herbivory, rainfall and density dependence. *J. Appl. Ecol.* **38**, 268–280.
- Scholes, R.J. & Archer, S.R. (1997). Tree–grass interactions in savannas. *Annu. Rev. Ecol. Syst.* **28**, 517–544.
- Seleshi, Y. & Zanke, U. (2004). Recent changes in rainfall and rainy days in Ethiopia. *Int. J. Climatol.* **24**, 973–983.
- Tefera S., Snyman, H.A. & Smit, G.N. (2007). Rangeland dynamics in southern Ethiopia: (1) Botanical composition of grasses and soil characteristics in relation to land-use and distance from water in semi-arid Borana rangelands. *J. Environ. Mgmt.* **85**, 429–442.
- Stattersfield, A.J., Crosby, M.J., Long, A.J. & Wege, D.C. (1998). *Endemic Bird Areas of the World: priorities for biodiversity conservation*. Cambridge: BirdLife International.

- Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H., Bishop, J.R.B. & Marques, T.A. (2006). *Distance 5.0. Release 2*. University of St. Andrews, UK: Research Unit for Wildlife Population Assessment.
- van Vegten, J.A. (1983). Thornbush invasion in a savanna ecosystem in eastern Botswana. *Vegetatio* **56**, 3–7.
- Walker, B.H., Ludwig, D., Hollin, C.S. & Peterman, R.M. (1981). Stability of semi-arid grazing systems. *J. Ecol.* **69**, 473–798.
- Ward, D. (2005). Do we understand the causes of bush encroachment in African savannas? *Afr. J. Range Forage Sci.* **22**, 101–105.
- Watson, E.E. (2003). Examining the potential of indigenous institutions for development: a perspective from Borana, Ethiopia. *Dev. Change* **34**, 287–309.
- Wondafrash, M. (2005). *A note on current conservation status of *Heteromirafra sidamoensis**. Unpublished report. Ethiopian Wildlife and Natural History Society.