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Assessing range-wide conservation status change in an unmonitored widespread African bird species

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ABSTRACT

Aim With the exception of South Africa there are no systematic, long-term, large-scale bird monitoring programmes in Africa, and for much of the continent the most comprehensive available data for most species are incidental occurrence records. Can such data be used to assess range-wide conservation status of widespread low-density species? We examine this using Kori Bustard *Ardeotis kori*, a large, easily identifiable species with an extensive African range.

Location Southern and East Africa, 14 countries.

Methods A comprehensive and systematic review of published and unpublished sources provided 1948 unique locality records spanning the years 1863–2009; these included 410 non-atlas records and 97 historical (pre-1970) records. Range-size changes were examined by comparing minimum convex polygons to quantify Extent of Occurrence pre- and post-1970, and by testing whether more historical records fell outside the recent (post-1970) 95% probability kernel than expected by chance. Additionally, qualitative evidence of changes in abundance was obtained from historical published accounts and contemporary assessments by in-country experts.

Results Since the late 19th century, range-size (measured as Extent of Occurrence) has contracted, by 21% in East Africa and 8% in southern Africa. There is strong qualitative evidence of considerable pre- and post-1970 population declines in all range states, except Zambia (slight increase) and Angola (trend unclear). In some countries, declines occurred from the early 1900s. Thus, while relatively modest change in range-size has occurred in over 100 years, numbers have greatly reduced throughout the species' range.

Main conclusions Our methodology allowed objective appraisal of continent-wide Kori status. Despite lacking quantitative population estimates and trends, and poor understanding of the species' autecology, common issues for many African species, incidental occurrence records can be used to assess range-wide changes in status. We recommend that this or similar approaches be applied to other widespread low-density species that probably also have rapidly declining populations despite apparently stable range extents.

Keywords

Africa, evidence-based conservation, geographic range change, Kori Bustard, Otididae, population decline, tropical.

INTRODUCTION

Evaluating the global conservation status of low-density widely distributed species poses many challenges. Assessments are particularly difficult in developing countries, where monitoring data are sparse (Balmford *et al.*, 2003). Uncertainty over older, unquantified statements on status, differences in type and extent of survey coverage between range states (countries in which the species occurs), geographic variations in abundance and habitat occupancy, and logistic

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difficulties in achieving range coverage (e.g. Houlahan *et al.*, 2000) often render status assessment of such species close to guesswork. While rapid declines raise international alarms by triggering IUCN Red List criteria (IUCN, 2001), as occurred for Indian vultures (Pain *et al.*, 2008), steady declines over long periods can go unrecognised and hence unremedied (e.g. Turvey *et al.*, 2010).

Range-wide changes in population size and extent in widely distributed African bird species have never been assessed quantitatively and systematically across multiple range states, although birds remain the continent's best-studied class of animals. Attempts at range-wide assessment (e.g. Beilfuss *et al.*, 2007; Ogada & Buij, 2011) have been largely descriptive, using analytical methodologies and data presentation formats that cannot readily be repeated. Objective baseline data remain sparse across most of the continent. In South Africa and Swaziland, the Southern African Bird Atlas Project 2 (www.sabap2.adu.org.za) collects standardized data on bird distribution and relative abundance, allowing distributional change from the Southern African Bird Atlas Project 1 in the 1990s (Harrison *et al.*, 1997) to be monitored. However, although bird atlases have summarized records in other African countries (e.g. Lewis & Pomeroy, 1989; Ash & Atkins, 2009), these often pool records across wide temporal spans (e.g. Carswell *et al.*, 2005) while none, including the rest of the southern African countries involved in Harrison *et al.* (1997), has been repeated to provide information on changing abundance or range. Quantitative, systematic analysis of population trends have been restricted to either one (e.g. Virani *et al.*, 2011) or a few adjacent countries (e.g. Simmons, 1996), not the entire geographic range. Repeating road transects after 20–30 years has demonstrated localized declines for some species (e.g. Thiollay, 2006; Virani *et al.*, 2011), but such monitoring has not involved larger spatial scales; other repeat transects, such as the Coordinated Avifaunal Roadcounts in parts of South Africa (Young *et al.*, 2003), have limited spatial and temporal coverage. Therefore, all that otherwise exist at continent-wide scales are distributional records and anecdotal assessments of abundance to be gleaned from publications, trip reports and museum specimen data. Could this material be combined with atlas data from discrete periods to evaluate conservation status change?

We examine this with respect to the Kori Bustard *Ardeotis kori*, a large-bodied, low-density species with an extensive African range. The Kori occurs as two taxonomically distinct populations: *A. k. kori* in southern Africa (Angola, Namibia, Botswana, Zambia, Zimbabwe, Mozambique and South Africa; extinct in Swaziland) and *A. k. struthiunculus* in East Africa (Somalia, Ethiopia, Sudan, Uganda, Kenya and Tanzania: Collar, 1996; Allan & Osborne, 2005). The species is thought to be experiencing range-wide decline (Collar *et al.*, 1986; Collar, 1996), and in South Africa, it has twice been listed as regionally 'Vulnerable' (Brooke, 1984; Anderson, 2000). Nevertheless, it is globally classified as Least Concern, because perceived population declines are thought not to meet the threshold of a 30% decline in 10 years or three generations necessary to achieve threatened status under IUCN Red List criteria (BirdLife International, 2008).

METHODS

Locality data

We analysed locality and demographic data from 1863 (earliest record) to December 2009. Locality records and reports on Kori distribution and population trends were obtained from documentary evidence, coupled with input from in-country experts. We undertook systematic literature searches, unrestricted by publication year, using the terms '*Ardeotis kori*', 'Kori Bustard', 'kori', 'Giant Bustard', 'Large Bustard', '*Choriotis kori*', '*Otis kori*', 'Outarde kori', 'Riesentrappe', 'Greater Bustard' and 'Avutarda Kori', in academic search engines (Scopus, Google Scholar, Web of Science), and reviewed reference lists of papers mentioning the species. We searched indices of *Zoological Record*, *Recent Ornithological Literature* (www.nmnh.si.edu/birdnet/rol), the three peer-reviewed African ornithological journals (*Bulletin of the African Bird Club*, *Ostrich* and *Scopus*), plus *African Journal of Ecology*, *Koedoe* and *South African Journal of Wildlife Research*, the tables of contents of Pan African Ornithological Congress proceedings, and newsletters from ornithological societies in countries in which the species occurs. We reviewed BirdLife International's online monitoring database (www.worldbirds.org), country and subregional bird atlases and, where accessible, expedition reports, site inventories, protected area management plans, checklists and project reports (see Table S1 in Supporting Information).

Spatial analyses

We adopted a coarse spatial resolution to accommodate imprecise locality data. Where authors did not provide coordinates of localities (e.g. 'near Somerset East, South Africa': Skead, 1968), we obtained coordinates of the nearest ($\leq$ 25 km) settlement or feature from the National Geospatial Intelligence Agency (www.geonames.nga.mil/ggmagaz/geonames4.asp); localities with location errors much > 25 km (e.g. 'seen along Umzimkhulwana River': Jonsson, 1973) were excluded from spatial analyses. National bird atlas data were resolved to the centroid coordinates of occupied sampling units, which varied in resolution from 10 km diameter point radii (Uganda) to 120 $\times$ 120 km grid-squares (Sudan). The Sudanese atlas provided only six occupancy points, while the majority of atlases used 50 $\times$ 50 km grid-squares (Table S1), for which the maximal error from centroids is 35 km, comparable to the spatial error of assigning imprecise locality records to mapped settlements and features.

Range-size of each subspecies was estimated as the mapped Extent of Occurrence (EOO; area of minimum convex polygon formed by outermost records) and, within this, the Area of Occupancy (AOO; *sensu* Gaston & Fuller, 2009) was calculated as the 95% density kernel of records (Worton, 1989). Kernel analysis was conducted assuming bivariate normal fixed kernels, using Home Range Tools for ArcGIS (version 1.1; Rodgers & Kie, 2010). Adaptive kernels overestimated range-size. Selecting a smoothing factor (Worton, 1989; Kenward, 2001) by Least Squares Cross-Validation failed, reverting instead to the reference smoothing factors h_{ref} (1.381 and 0.985 for southern and East Africa respectively). Therefore, to minimize over-smoothing, we followed the *ad hoc* approach of Rodgers & Kie (2010), testing values from 0.2 to 1.6 times h_{ref}, in increments of 0.05, and accepted the minimal value for which the outer 95% kernel contour remained continuous and uninterrupted. This provided smoothing factors of 1.036 (i.e. $0.75*h_{ref}$) and 0.985 (i.e. h_{ref}) for the southern and East African subspecies, respectively. The resolution of the largest atlas grid-squares was 2500 km^2 for southern Africa (Botswana), but 14,400 km^2 for East Africa (Sudan; Table S1); range extents were therefore rounded to a resolution of 10,000 km^2, to make measures of range change for the two regions comparable. The AOO and EOO estimates were calculated from UTM coordinates of grid centroids, and therefore avoided any bias from changing linear dimensions of grids, particularly at lower latitudes. This lack of bias is because (1) for AOO, kernel estimators are insensitive to the resolution of the input data (Kenward, 2001), and (2) when calculating EOO, for atlas records that constitute the minimum convex polygon, the geographic centres of occupied grid cells are used, which means that the absolute size of the grid cell is irrelevant.

We chose 1970 as the threshold date for comparing range-size and abundance trends, as some bird atlases are based on records from 1970 onwards, although others date from the 1980s and 1990s (Table S1). We computed the maximum recorded (1863–2009) and 'recent' (post-1970) EOO separately for each subspecies. The difference in overall EOO between these periods was taken as a crude measure of range change, following Burgman & Fox (2003); IUCN (2001) also typically uses changes in EOO to infer trends in range-size.

To investigate potential range contractions while controlling for both temporal and spatial survey effort, we tested whether the proportion of historical records outside the recent AOO was greater than random. Whether the proportion of historical (pre-1970) records lying outside the recent 95% density kernel (buffered by 85 km, the maximal location error from the coarsest atlas grid-squares: 120 × 120 km) exceeded 5% was tested using a one-tailed chi-square goodness-of-fit test. We first assessed the validity of each historical record located outside the recent 95% range kernel estimate, by consulting in-country experts and reviewing the strength of evidence for purported records. We recognize that, given sparse historical records (< 100) and thus limited statistical power, this is a conservative test of range contraction.

We used ArcGIS version 9.3 for geospatial analysis and SPSS version 16.0 (SPSS Inc., Chicago, IL, USA) for statistical analysis. Data are presented as mean ± SD.

Data quality

Despite civil conflicts in some range states, these did not cause any obvious gaps in survey effort (Appendix S1) with the exception of Angola. We therefore report tests of range changes with and without Angolan data. Unlike southern Africa atlases, those from East Africa were not based on systematic surveys of grid-squares (Table S1). To assess whether Kori range boundaries derived from these atlases were artefacts of incomplete coverage, we inferred observer presence in apparently unoccupied grid-squares at the Kori range margin by examining records for 10 other conspicuous, widely distributed bird species (Appendix S1) whose ranges (in Stevenson & Fanshawe, 2004) encompass the relevant grid-squares.

Population trends

Qualitative evidence of population trends was obtained by reviewing published material and using questionnaires to collate contemporary in-country expert opinion.

To infer pre-1970 trends, we collated all published statements located during the systematic literature review in which authors made explicit reference to Kori numbers and scored the evidence as weak or strong, and the degree of change as substantial decline, slight decline, no change, slight increase, substantial increase, or trend unknown.

To assess post-1970 trends, we reviewed published material reporting country-wide Kori numbers. Some material provided national population estimates; we report these and the applicable time-periods. In-country experts, comprising atlas coordinators, bustard researchers and active ornithologists, were asked to assess (1) national or subnational trends in numbers and range, (2) factors causing these trends, (3) quality of data underlying their assessments and (4) time-periods over which their estimates apply (Appendix S2). To avoid cognitive bias or exaggeration of trends among respondents, the covering letter and accompanying questionnaire did not suggest expectation of decline versus increase or suggest concern over the status of Kori. This analysis excluded Swaziland, where Kori went extinct pre-1970 (Parker, 1994), and Zambia, which had only six records (Dowsett, 2009). We aimed to solicit input from at least three experts for each country in which the species occurs.

RESULTS

Historical and current distribution

We collated 2248 locality records, 1853 (82%) from published sources and 395 (18%) from BirdLife International's online monitoring database, the latter only populated for Botswana (n = 308) and Kenya (n = 87). The 2248 records were combined to provide 1948 unique records for one locality (or grid-square, for countries with atlases) within one calendar year. Of all unique records, 1538 (79%) were from atlases, and more (1355; 70%) were for *A. k. kori*, largely owing to finer spatial resolution and greater geographic coverage in southern African atlases. Post-1970 records (Fig. S1) totalled 1851 (95%; Table S1); pre-1970 records totalled 97. All data are available electronically from the corresponding author.

We estimated recent (post-1970) EOO to be 4,060,000 km^2 (southern Africa 2,680,000 km^2; East Africa 1,380,000 km^2). The AOO enclosed by the 95% kernel was estimated at 3,420,000 km^2 (southern Africa 2,230,000 km^2; East Africa 1,190,000 km^2). The historical EOO, omitting localities 1–3 in Fig. 1(a) which had insufficient supporting evidence (Table 1) and were excluded from subsequent analysis, was estimated at 4,652,000 km^2 (southern Africa 2,900,000 km^2; East Africa 1,752,000 km^2).

Post-1970 range limits in East Africa are unlikely to have been affected by the lack of systematic grid-based surveys during atlas compilation, as many co-occurring widely distributed and conspicuous species were recorded from grid-squares bordering Kori range margins (Appendix S1). The recent Kori range-core largely overlapped the Great Rift Valley, with a narrow and generally continuous range. An exception was the subpopulation in south-east Ethiopia (Fig. 1a), which was probably genuinely disjunct rather than an artefact of observer effort, as co-occurring widely distributed species were reported from nine of the 12 grid-squares surrounding it (mean 3 ± 2 SD species; range 0–6 species per 50-km grid-square), and its minimum distance to the range-core kernel was approximately 200 km. There were at least three localities where the range of *A. k. struthiunculus* was constrained to a single 50-km-wide occupied grid-square (localities A, B and C in Fig. 1a); except in Kenya (Lewis & Pomeroy, 1989), these potential narrow bottlenecks appear to be long-standing.

Nominate *A. k. kori* has been recorded in Angola, Namibia, Botswana, Zambia, Zimbabwe, South Africa, Mozambique and, in the 1950s, Swaziland. The paucity of records ($n = 5$) precluded inference of historical and current range limits in Angola, although Dean (2000) suggested that the northernmost recent record coincided with the arid belt boundary at 16°S. Kori only marginally extended into Zambia: all six published records, the earliest in 1997 (Dowsett, 2009), were within 20 km of the northernmost records in Botswana and Zimbabwe. The recent Kori range enclosed all of Namibia and Botswana, much of western South Africa, but notably not south-east South Africa. Elsewhere in South Africa Kori mainly occupied areas bordering Botswana and Zimbabwe and southwards to Kruger National Park, including areas adjoining this park inside Mozambique. In Zimbabwe, although the range extended north to 16°S, there was a gap (50–150 km; Fig. 1b) from south-west to north-east along the extensively cultivated and hence probably unsuitable 'central plateau' (Rockingham-Gill, 1983).

Range-size change

Since the 19th century, there has been a modest Kori range contraction, notably in East Africa within Somalia, Tanzania

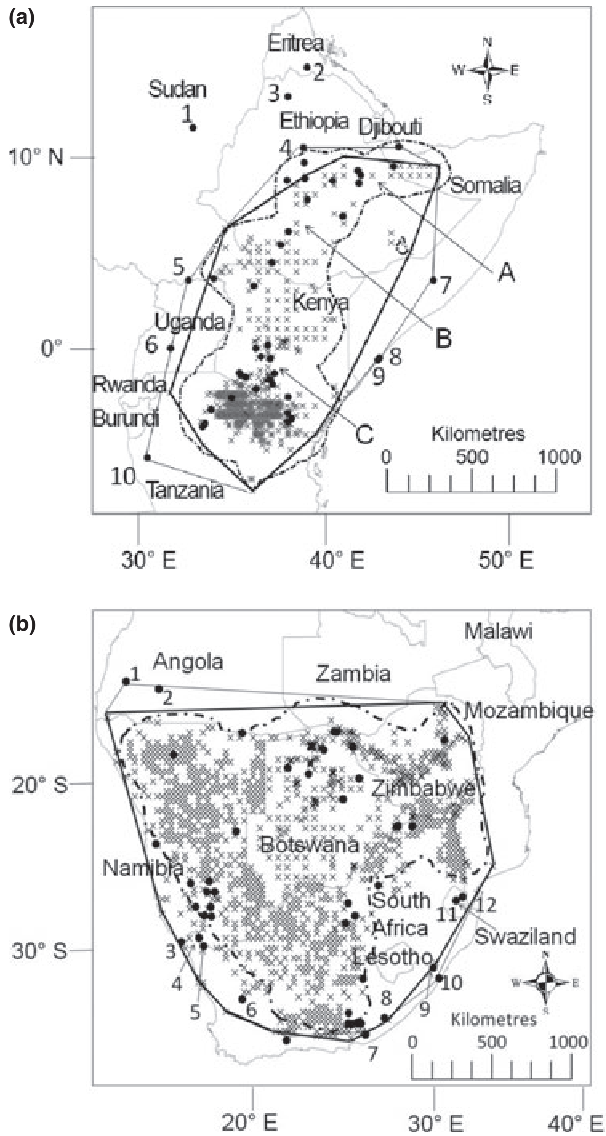

Figure 1 Kori Bustard *Ardeotis kori* distribution in (a) East Africa and (b) southern Africa from collated sightings, hunting and museum records and atlas data. ● pre-1970; × post-1970 (atlas and other records). Atlas records are the coordinates of centres of all occupied grid-squares in atlases listed in Table S1. Geographic range boundaries are represented as the minimum convex polygon enclosing all confirmed sightings spanning the years 1863–2009 (—) or only post-1970 data (**—**) and 95% kernel density estimate (bivariate normal fixed kernels, smoothing factor $h = 1.036$ and 0.985 for southern and East Africa, respectively) for post-1970 data (-··-·). Numbered localities are all pre-1970 point localities falling outside the subspecies-specific 95% kernels and are detailed in Table 1; East African localities 1–3 are excluded from range loss calculations as they are misidentified Kori. Arrows indicate the three localities where range-extent is limited to one confirmed occupied 50-km-wide grid-square: A, east of Harar (Ethiopia); B, Misraq Shewa Zone of the Oromia Region, south of Addis Ababa (Ethiopia); C, Nairobi–Nakuru (Kenya).

Table 1 Historical (pre-1970) Kori Bustard *Ardeotis kori* locality records outside the 95% kernel of recent (post-1970) geographic range. Mapped location of these numbered extralimital records are shown in relation to the kernels in Fig. 1(a,b).

Subspecies	Record	Year	Locality name	Source	Record reliability and relevance
A. k. struthiunculus	1*	1901	Renk, Sudan	Ogilvie-Grant (1902)	Specimen at the British Natural History Museum is in fact a misidentified *Ardeotis arabs* (G. Nikolaus pers. comm.).
	2*	Undated, pre-1944	Mendefera, Eritrea	Moltoni & Ruscone (1944)	Probably misidentified *A. arabs* given no other *A. kori* record from Eritrea; excluded from analysis.
	3*	Undated, pre-1944	Amba Ghermie, Ethiopia	Moltoni & Ruscone (1944)	Lacks supporting details (Ash & Atkins, 2009); excluded from analysis, more than 300 km from northernmost confirmed records; probably a misidentified *A. arabs*.
	4	Undated, pre-1944	Wobok, Ethiopia	Moltoni & Ruscone (1944)	Occupied atlas grid-square (Ash & Atkins, 2009). Lacks supporting details, but < 25 km from northernmost confirmed records; included in analysis.
	5	January 1949	Acholi-Lango border, Uganda	Carswell *et al.* (2005)	Record accepted by Carswell *et al.* (2005). Very probably genuine, especially in light of *A. kori* 'common in north-eastern Uganda, on areas < 2000 m above sea level' (van Someren, 1933).
	6†	Undated, pre-1938	Ankole, Uganda	Jackson (1938); Carswell *et al.* (2005)	No primary source; hunting report to Jackson (1938). Area 'well grassed' (Friedmann & Loveridge, 1937), typical of presumed *A. kori* habitat (Collar, 1996). Record < 100 km from confirmed records in north-west Tanzania (Fig. 1a). Record accepted here, given no other large bustards in the area; may represent extinct Ugandan subpopulation or visitors from Tanzania.
	7†	Undated, pre-1944	Harar, Somalia	Moltoni & Ruscone (1944)	No primary source, but given proximity to extant Ethiopian subpopulation, record probably genuine but subpopulation now possibly extinct.
	8†	Undated, pre-1944	Giumbo, Somalia	Moltoni & Ruscone (1944)	Accepted records in Ash & Miskell (1998); no reports from area since 1950s.
	9†	Undated, pre-1944	Chisimaio plains, Somalia	Moltoni & Ruscone (1944)	Accepted records in Ash & Miskell (1998); no reports from area since 1950s.
	10†	1921	Mlenga, Tanzania	Friedmann & Loveridge (1937)	Reported by A. Loveridge who in 1920s collected many Kori specimens for Museum of Comparative Zoology, Boston, MA, thus improbably misidentified. No recent records from area (Baker *et al.*, in prep.); probably a genuine range contraction.
A. k. kori	1†	1860s	Humbe, Angola	Traylor (1963)	Specimen collected by Bocage in 1860s; present status unclear (Dean, 2000)
	2†	Pre-1960s	Mulondo, Angola	Dean (2000)	Genuine record (Dean, 2000). Pinto's 1960 report misspelt as Mulundo, outside predicted Angolan range (R. Dean pers. comm.); present status unclear (Dean, 2000).
	3	1943	Orangemund, Namibia	Plowes (1943)	Enclosed within EOO based on post-1990 data; no influence on overall range boundary.
	4	1956–1959	Aussenkjer, Namibia	Maclean (1960)	No range decline; < 20 km from recent records (Harrison *et al.*, 1997).
	5	1956–1959	Viool's Drift, Namibia	Maclean (1960)	Enclosed within EOO based on post-1990 data; no influence on overall range boundary.

Table 1 (Continued)

Subspecies	Record	Year	Locality name	Source	Record reliability and relevance
	6	1954	Calvinia, South Africa	Skead (1955)	No range decline; < 40 km from recent records (Harrison *et al.*, 1997).
	7	1960s	Grahamstown, South Africa	Skead (1967)	No range decline; < 20 km from recent records (Harrison *et al.*, 1997).
	8	1863	Umgwali Reserve, South Africa	Jonsson (1973)	Enclosed within EOO based on post-1990 data, no range decline; < 20 km from 1992 records (Colahan, 1993).
	9†	1863	Richmond, South Africa	Jonsson (1973)	Locality < 20 km from a recent (Harrison *et al.*, 1997) record. While Harrison *et al.* (1997) argue all *A. kori* records in this region may refer to misidentified Denham's Bustard *Neotis denhami*, Cyrus & Robson (1980), with data collection 1970–1979, included Kori in list of 'rarer species and vagrants', with a confirmed Pietermaritzburg record (1976). This 1976 record results in recent EOO encompassing Richmond, but abundance appears drastically reduced relative to 1862–1863, when 'lots of Pou [*colloquial for bustard*] were shot near Richmond' (Jonsson, 1973). Despite possible confusion with *N. denhami*, Kori population seems to have declined.
	10†	1863	Ifafa, South Africa	Jonsson (1973)	Approximately 60 km from locality 9; status and relevance the same.
	11	Pre-1960	Mafutseni, Swaziland	Parker (1994)	R. Girwood and R. Hardin (pers. comm. to Parker, 1994). Occurred more widely around this locality, but unrecorded post-1960, including during monthly atlas field surveys 1985–1991.
	12	Pre-1960	Hlane Royal National Park, Swaziland	Parker (1994)	R. Girwood and R. Hardin (pers. comm. to Parker, 1994). Unrecorded post-1960, including during monthly atlas field surveys 1985–1991.

EOO, Extent of Occurrence.
*Rejected records.
†Reliable records falling outside the 85 km-buffered kernels.

and Uganda (Fig. 1a). Differences between historical and recent EOO suggested 21% and 8% declines in East and southern Africa, respectively.

For East African Kori, marginally more reliable historical records occurred outside the buffered recent 95% kernel (5/48: localities 6–10, Fig. 1a) than expected by chance, given the density distribution of recent records ($\chi^2 = 2.965$, d.f. = 1, $P = 0.085$). These five extralimital historical records were a mean 150 km ± 30 SD outside the buffered kernel, and an average 290 km ± 50 SD from the nearest recent record. This apparent decline is supported by strong qualitative evidence for historical range contractions. In the early 1920s, Kori was still 'occasionally seen' in Jubaland (south-westernmost Somalia province: Clifford, 1928), but was locally extirpated before 1950 (Ash & Miskell, 1998). In Kenya, local extinctions occurred east and west of Nairobi, and in the south-east (east of Mt Kenya, and in the Mombasa area), leaving a seemingly disjunct population on the lower Tana River (Lewis & Pomeroy, 1989). Elsewhere in East Africa, the isolated subpopulations in south-west (Ankole region) and northern Uganda (Acholi region) and south-west Tanzania appear to have died out: for example, for north-east Uganda van Someren (1933) stated 'Kori common', but there are no recent records (Carswell *et al.*, 2005).

For southern African Kori, the proportion of historical records outside the buffered recent 95% kernel (4/49) was similar to that expected by chance ($\chi^2 = 1.032$, d.f. = 1, $P = 0.310$). Distances between all historical extralimital records and the recent buffered kernel boundary were similar to those for extralimital East African records (mean 180 km ± 90 SD, $t = 0.815$, d.f. = 7, $P = 0.442$), but extra-limital historical records were located closer to recent records than in East Africa (130 km ± 90 SD, $t = 3.395$, d.f. = 7, $P = 0.012$). This difference was not because of the coarser

East African atlas grid-squares. Coordinates of the closest recent records were derived from atlases where the maximal error from using grid-square centroids was 35 km (n = 4, localities 6–9, Fig. 1a) or 8 km (n = 1, locality 10) for East Africa, and 18 km for all four southern Africa records (localities 1, 2, 9 and 10, Fig. 1b, Table S1). Extralimital historical records in East Africa were still located further from recent records, even after adjusting proximity measures in southern Africa by the maximum difference in grid resolution, by adding 17 km (t = 2.967, d.f. = 7, P = 0.021).

In southern Africa real range contraction probably occurred only in Swaziland and south-east South Africa, based on a lack of post-1970 records from these regions (Fig. 1b); this is corroborated by the only available qualitative evidence of historical large-scale range loss in the subregion (Astley-Maberly, 1937; Parker, 1994; Table 2). Trends in Mozambique and Angola were unclear. Parker (1999) suggested the Mozambique range was always restricted to areas bordering Kruger National Park, although the time-period over which this assessment applied was not stated (probably largely post-1970). Four of the five Angolan records (three pre-1970, two post-1970) fell outside the kernel boundary (one pre-1970 record was within), but this was probably an artefact of the kernel estimator properties. Owing to the small sample size, large inter-locality distances and remoteness, these records were excluded from the parsimonious kernel that captures 95% of record density in the smallest possible areal extent. When historical Angolan records were excluded from chi-square tests, the proportion of extralimital localities (2/47) was similar to that expected by chance (χ^2 = 0.055, d.f. = 1, P = 0.815), providing further evidence for minimal large-scale contraction in southern Africa.

Population trends

Although quantitative data suitable to examine whether population declines had occurred were not available for any range state, reported qualitative trends provided a strong indication of subregional and global-level declines in abundance. Subjective published demographic assessments suggested declines within 12 of the 14 countries in which Kori occurs, both pre- and post-1970 (Tables 2 and 3). Of 16 inferred pre-1970 trends from published assessments, 11 were negative or strongly negative. Published subjective abundance indices and qualitative comments on trends together suggest that in some countries (e.g. South Africa and Zimbabwe), declines occurred from the early 1900s (Table 2).

Published assessments suggest that Kori population numbers continued to decline post-1970 in six of six East African and six of eight southern African range states; the exceptions were Zambia and Angola (Table 3, Fig. 2). However, all six Zambian records (in all but one case singletons) were from 1997 to 1999 (Dowsett, 2009), so any apparent population increase may have been temporary. While only five records were available from Angola (Table S1), expert opinion suggested a larger population exists there (W. R. J. Dean & P. Vaz Pinto pers. comm.), although trends were unclear (Dean, 2000).

Nineteen of the 55 respondents contacted provided information on post-1970 Kori trends in abundance and range-size, with 12 making national-level assessments (three for Angola; two for Kenya and Ethiopia; one for Namibia, Mozambique, Tanzania, Uganda and Somalia; Appendix S3). Seven commented on trends at provincial or site-levels, mostly protected areas. Responses were subjective in most instances, but in South Africa, they were supplemented by published data (Tarboton et al., 1987).

Expert opinion from the 12 range states assessed suggested that post-1970 Kori numbers have declined or are at best unchanged; of the 12 respondents providing information on national-level trends, four (33%) reported declines (two substantial, with more than 50% decline; two slight), six considered trends uncertain, two reported no change and none reported increases. Two reported no change in concomitant range-size, six were uncertain and four suggested range contraction.

Published post-1970 Kori population estimates were available from only three southern African range states (Table 3). However, all population numbers are best guesses and none of the sources provided underlying evidence; thus, any future assessment of population trend against these estimates will require caution.

DISCUSSION

Changes in abundance and range-size in unmonitored widespread species can be systematically evaluated without comparing occupancy patterns between atlases (e.g. Gibbons et al., 2007; Robertson et al., 2010) or field surveys (e.g. Riou et al., 2011). It was possible to calculate historical and recent EOO, and recent AOO, using national atlas data, incidental records and other published sources. Range boundaries were validated by inferring observer coverage from the distribution of co-occurring species. Although non-systematic records prior to the period of atlas compilation were sparse, by formally testing the distribution of such records against the 95% density kernel of more abundant recent records, we were able to test whether range contraction had occurred. Systematic review of published sources provided strong qualitative evidence of declines in abundance and localized reductions in range. Questionnaire responses provided further qualitative evidence of recent trends in abundance.

Trends in Kori population and range-size

Data-screening and quality control are critical steps in evidence-based status assessment, particularly for widespread low-density species whose ranges straddle multiple countries. Verification of locality records revealed some misleading historical records from central Sudan, Eritrea and northern Ethiopia which inflated the true historical range of *A. k. struthiunculus*.

Table 2 Assessment of pre-1970 Kori Bustard *Ardeotis kori* population trends from published literature. Only publications where authors explicitly comment on trends are reported, along with corresponding spatial extent and time-period. Quality of evidence is assessed as weak/strong based on the authors' confidence in ascertaining trends. Degree of purported population change is classed as: ≈, uncertain trend; =, no evidence for population change; −, slight decline; −−, substantial decline; +, slight increase; ++, substantial increase. No assessments reported any increase.

Spatial extent	Time-period	Statement on population trend	Quality of evidence	Inferred trend	Source
Natal Province, South Africa	1860s	'Must have been abundant in Natal during early 1860s … based on Dobie's Diary (Hattersley, 1945)'.	Weak	−−	Jonsson (1973)
Kroonstad District, Free State Province, South Africa	1870s–1907	'Rarely seen here now, though it was never common'.	Strong	−−	Symonds (1907)
South Africa	1900–1970	'Numbers less than they were a century and more ago but the extent of reduction unknown'.	Weak	−	Brooke (1984)
Present-day Mashonaland East Province, Zimbabwe	Pre-1930s	'Although fairly plentiful in the Beatrice District in the past, by 1930 it was seldom seen and likely to go locally extinct in a few years'.	Strong	−−	Krienke (1931)
Eastwards of Johannesburg up to border with Swaziland and Mozambique, South Africa	1920s	'Even by 1925, when Kruger National Park was established, the bird had already lost much of its range in South Africa's Highveld region, mainly because of considerable persecution'.	Strong	−−	Astley-Maberly (1937)
South Africa and Zimbabwe	1940s–1950	'In Southern Africa reported as decreasing at a dangerous rate'.	Weak	−−	Lynn-Allen (1951)
Swaziland	Pre-1960	'Hunted to local extinction prior to 1960, with subsequent bush encroachment of its former range making it impossible for re-colonization'.	Strong	−−	Parker (1994)
Eastern Cape Province, South Africa	1962–1967	'Status uncertain because of confusion with Stanley's Bustard *Neotis denhami* and Ludwig's Bustard *Neotis ludwigii.* If most identifications are correct, *A. kori* has considerably weakened in status'.	Weak	−−	Skead (1967)
Eastern Cape Province, South Africa	1960s	'Has probably declined in the Eastern Cape'.	Weak	−	Clancey (1972)
North of Windhoek, Namibia	1960s	'Status satisfactory in northern Namibia, and there is no evidence for decline'.	Weak	=	Clancey (1972)
Botswana	1960s–1970	'No evidence for decline', author citing June 1970 pers. comm. with R.H.N. Smithers.	Weak	=	Clancey (1972)
Zimbabwe	1960s–1970	'Regarded as holding its own', author citing June 1970 pers. comm. with M.P.S. Irwin.	Weak	≈	Clancey (1972)
Free State Province, South Africa	1960s–1970s	'Present status in province unclear'.	Weak	≈	Clancey (1972)
Somalia, Kenya and Tanzania	1940s–1950	'In the wilder parts of Somalia, Northern Frontier Province and Turkana in Kenya and in Northern Tanganyika Kori still very plentiful'.	Weak	≈	Lynn-Allen (1951)
Ethiopia	1960s–1970	'Formerly fairly common south of *Ardeotis arabs* range (the two almost entirely allopatric) in less arid areas'.	Strong	−	Ash (1989)
Somalia	1960s–1970	'Previously fairly common in open bush country and grassy plains of the northwest, south to about 9°-N and east to 46°-E, but no recent records'.	Strong	−−	Ash (1989)

Table 3 Post-1970 population estimates and trends for Kori Bustard *Ardeotis kori*, collated from published accounts in each range state.

Subspecies	Country	Population estimate (year)	Population trend (time-period)*	Source
Ardeotis k. kori	Angola	None	Unclear (1970s–2000)	Dean (2000)
	Botswana	None	Decline (1990–2005)	Tyler (2005)
	Mozambique	< 100† (1999)	Decline (1970s–1999)	Parker (1999)
	Namibia	None	Decline (1990s–2000)	T. Osborne & L. Osborne (unpublished data)
	South Africa	2000–5000 (2000)	Decline (1980s–2000)	Anderson (2000)
	Swaziland	0 (1994)	Decline, extinct in 1950s	Parker (1994)
	Zambia	None	Range expansion; slight population increase (1997–present)	Dowsett (2009)
	Zimbabwe	10,700 (1980), 2000 (1989), 5000 (1990)	Decline (1980s–1990)	Rockingham-Gill (1983); Mundy (1989); Dale (1990)
	Subregion	None		
Ardeotis k. struthiunculus	Ethiopia	None	Decline (1980s–2009)	Ash & Atkins (2009)
	Kenya	None	Decline (1970s–1989)	Lewis & Pomeroy (1989)
	Somalia	None	Decline (1970s–1998)	Ash & Miskell (1998)
	Sudan	None	Decline (1976–1989)	Nikolaus (1987)
	Tanzania	None	Decline (1970s–present)	Baker *et al.* Tanzania Bird Atlas (in prep.)
	Uganda	None	Decline, possibly locally extinct in 1970s‡	Carswell *et al.* (2005)
	Subregion	None		
	Entire range	None		

*All of the suggested population trends are based on the personal opinions of authors of cited literature sources, none of whom provide supporting documentary evidence (except for Swaziland, where atlas fieldwork did not report any Kori, proving strong evidence of genuine localized extinction).

†This estimate is for southern Mozambique, south of the Save River. Kori have only been reported from this region, thus this estimate is effectively a country estimate.

‡However, there are recent (post-2000) reports from Kidepo National Park in north-east Uganda along the border with Sudan (H. Kemigisha & A. Byaruhanga pers. comm.).

Although Kori populations declined in both subregions during the period 1863–2009 (Tables 2 and 3), overall range-sizes (measured as EOO) did not, being moderately reduced in East Africa and largely unchanged in southern Africa. At the species scale, range contraction was 13% over more than 100 years, based on contrasts of pre- and post-1970 EOO. However, the continued contemporary occupation of the atlas-based range is difficult to gauge, owing to (1) the use of 1970s–1980s data in post-1990 atlases and (2) sparse data since some earlier atlases (e.g. no published information on Sudanese Kori post-1989). Our analysis was, therefore, unable to examine whether more recent range contractions have also occurred. However, further contraction is unlikely to have exceeded 30% (the weakest Red List threshold: IUCN, 2001) over the period 1965–2010 (approximately three generations for *Ardeotis* bustards: S. H. M. Butchart pers. comm.), given both the strong spatial similarity of post-1990 atlas records to records from the 1960s and 1970s and qualitative evidence from survey respondents suggesting no dramatic post-1980 distributional change. Consequently, solely on the basis of range contraction, the Kori's current listing as Least Concern (BirdLife International, 2008) is not inappropriate. Nevertheless, there is extensive qualitative evidence for overall population decline and profound change in the internal characteristics of the Kori's range, ongoing since at least the early 20th century. It is disquieting that this has occurred without being registered as a significant issue for the conservation of the species.

The causes of overall population declines and range losses in south-east South Africa, south-west Somalia, south-west Tanzania and south-west and northern Uganda are unknown. Hypothesized factors include persecution (Astley-Maberly, 1937; Porter, 1949; Herremans, 1998) and impacts of rangeland degradation and shrub encroachment (Collar, 1996; Ash & Miskell, 1998; Herremans, 1998), but these have not been investigated in any range states except Botswana, where findings suggest unregulated hunting is a genuine threat while cattle-induced bush encroachment is not (Senyatso, 2011).

The seemingly discrepant severity of range loss between the eastern and southern subspecies, as measured by historical and recent EOOs, is not an artefact of coarser atlas grid-square resolution in East Africa. Range loss was most distinct in south-west and northern Uganda, south-west Somalia and

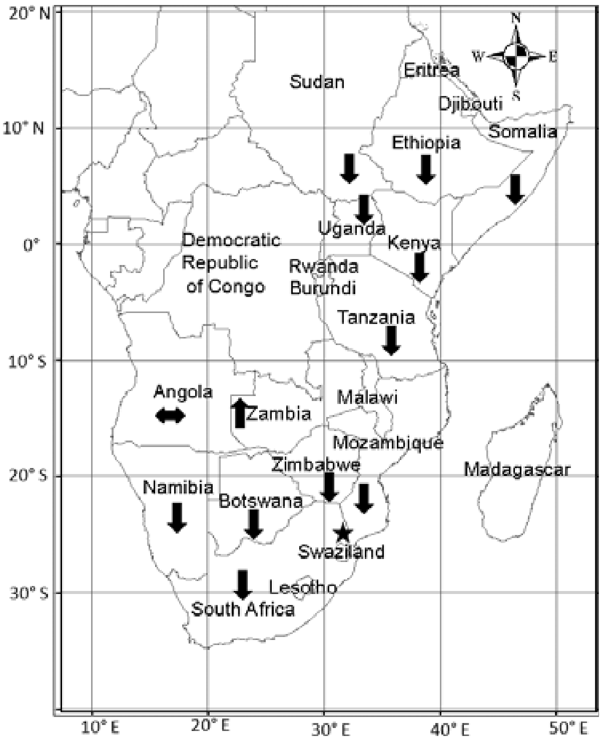

Figure 2 Kori Bustard *Ardeotis kori* population trends in each range state during 1970–2009 based on published sources and in-country expert opinion. ★ Strong evidence for possible local extinction; ⬇ strong qualitative evidence for population decline; ⬄ population trend unclear; ⬆ strong qualitative evidence for population increase. None of the range states has quantitative estimates of population decline.

western Tanzania, where apparently isolated subpopulations were extirpated. All East African extralimital historical records outside the current AOO were obtained either from much-visited national parks or within 50 km of settled areas, so recent Kori absence from these localities is unlikely to be attributable to lack of observation effort.

Influence of spatio-temporal sampling effort and data resolution

How robust was our methodology to variations in search and sampling bias and spatial scale? Our approach overcame several statistical issues resulting from uneven spatial and temporal sampling effort within and across countries in which the species occurs, which might otherwise have compromised the analysis of occurrence records collated through search strategies of the type used in this study. Here we discuss five potential limitations to the methodological approach.

First, there was more sampling effort for Kori in protected than unprotected areas. At site level, this bias was reduced by subsuming all records inside one calendar year into a single entry. At national level, where atlas data are available, grid-squares cover the whole country, and the 95% kernel was largely based on these extensive datasets. In countries without geo-referenced atlases (Angola and Zambia), fewer than 10 records were collated, so any bias towards protected areas was unlikely to influence subregional range estimates significantly.

Second, animal detectability and observer-favoured sampling sites vary with vegetation type and accessibility, increasing the potential for under-reporting in more wooded or harder-to-reach areas. However, the coarse spatial scale of analysis reduced finer-scale errors resulting from preferential sampling along roads or habitats offering better visibility.

Third, there were differences in sampling effort between the two time-periods, because effort increased greatly with time throughout the range (Fig. S1). However, testing whether more historical records occurred outside the current AOO than expected by chance was robust, although conservative. Although the long time-periods used here compromised temporal resolution, they ensured that the recent range boundaries, against which decline was measured, were delineated from the best available data. Our results are robust largely because kernel estimators are not sensitive to (1) different in-country sample sizes (robust if more than 30 data points are used, which also meant that the different sample sizes between the East and southern Africa locality records introduced no directional bias), (2) range-size or shape and (3) spatial resolution of input data (Kenward, 2001). Our use of kernel estimators is an improvement on methods solely involving minimum convex polygons, whose estimates can be biased by sample size and range shape (Burgman & Fox, 2003). However, sparse historical records (48 and 49 records for the East and southern subspecies respectively) meant that the test of whether more occurred outside the recent AOO than expected by chance had limited statistical power and was therefore highly conservative; but an equal number of pre-1970 records for the two regions meant that any sample-size driven bias was comparable across the regions. Moreover, our EOO-based estimates of range-extent loss probably represent the minimum area lost, owing to a lack of information on whether any disjunctions or discontinuities were created post-1970, and because the low numbers of pre-1970 records may have underestimated historical EOO.

Fourth, however, at local scales, our 95% kernels probably overestimated true recent AOO owing to the coarse spatial resolution used, so that any increased perforation of continuously occupied range could not be detected. Moreover, our estimates of distributional limits and buffers around kernels are conservative and possibly underplay range contractions; for example, although the recent range limits in southern Africa are fairly robust, being based on extensive and systematic atlasing (e.g. Harrison *et al.*, 1997; Parker, 1999), we still buffered them by 85 km, equivalent to approximately two to three times the dimension of some of the subregion's atlas grid-squares (Table S1). Similarly, we rounded range estimates to 10,000 km^2 based on the coarsest atlas resolution (Sudan), although that country contributed only six occupancy records, and most countries had atlases with resolutions smaller than half that of the Sudanese atlas (Table S1).

Fifth, as outlying localities disproportionately affect range estimates, our method of assessing changes in range-extent may be affected by temporary movements beyond the typical range of a species. This problem was considered negligible for Kori, because estimates of individual home-range (Namibia: median 272 km^2, $n = 16$, Osborne & Osborne, 1999; Kenya: approximately 300 km^2, $n = 1$, Njoroge & Launay, 1998; Botswana: 528 $km^2 \pm 574$ SD, $n = 6$, Senyatso, 2011) are similar to that of the coarsest locality data in this study. Moreover, satellite telemetry showed female Kori in central Botswana to be sedentary (Senyatso, 2011). For such species, localized population declines will cause range contractions. It is, however, possible that when using kernel estimators to determine changes in AOO for highly fragmented or perforated ranges, the real decline in occupied range may be far greater than the kernels suggest. Notwithstanding, where data density and resolution permit, kernel estimators may allow the delineation of such fragmented and non-contiguous ranges through adjusting the kernel-smoothing factor (Worton, 1989). However, for strongly migratory, dispersive or nomadic species population trends and apparent range-size may be decoupled (Gaston, 2003).

We acknowledge that demonstrating long-term Kori decline required an extensive exercise in data-gathering and analysis. Such work is greatly intensified if different in-country experts are sought to validate records or provide trend evidence for different subpopulations. Using only expert-interviews would reduce effort required to complete assessments, but such appraisals remain possible only for a few species, particularly those not prone to misidentifications in the field or subject to recent taxonomic revisions (e.g. Turvey *et al.*, 2010), and where the number of experts is not likely to be limited. Moreover, for species with ranges as large as the Kori's, expert-interviews alone cannot be used for range-wide assessments that permit fine-scale spatial analysis, because the assumption that informants continuously 'surveyed' wildlife at multiple fine-scale localities throughout the geographic extent and the period of interest would less probably be met.

Conservation implications

Widespread low-density species may experience steady, pervasive and virtually undetected declines in abundance without showing obvious commensurate range collapse (Rodríguez, 2002; Turvey *et al.*, 2010). Methods are therefore urgently needed for objective range-wide status assessments of such species. While systematic monitoring based on repeat survey or atlas work is an important long-term goal (e.g. Telfer *et al.*, 2002; Pollock, 2006; Robertson *et al.*, 2010), the conservation value of shorter-term assessments in the absence of such information is obvious. It is not appropriate to use studies that have only measured local abundance or relations between habitat and density to extrapolate range-wide (e.g. Tobias & Brightsmith, 2007) or even country-wide (e.g. Gros, 2002) population size or patterns of population trend or abundance. Problems with such approaches include variation in wildlife-habitat association (Whittingham *et al.*, 2005), for example, arising from patchily distributed conservation effort (Gray *et al.*, 2009). Consequently, ecologists in developing countries may need to assess range-wide conservation status using incidental rather than systematic distributional or census data from localized scales. Within the caveats discussed, our methodology may be especially valuable for key indicator species, and its transferability (for instance, to flocking rather than solitary species that are thought to be declining, such as Southern Ground Hornbill *Bucorvus leadbeateri*: Vernon & Herremans, 1997) needs investigation. Further testing of our methodology and similar approaches on other widespread low-density species is strongly recommended, particularly in regions without systematic monitoring programmes.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table S1 Number, source and period (pre- or post-1970) of unique locality records.

Figure S1 Cumulative total of unique locality records.

Appendix S1 Data quality.

Appendix S2 Questionnaire sent to in-country experts to solicit opinions on Kori Bustard population numbers and geographic range.

Appendix S3 Responses to questionnaire sent to in-country experts.

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