SEASONAL CHANGES IN HOUBARA BUSTARD *Chlamydotis undulata macqueenii* NUMBERS IN HARRAT AL HARRAH, SAUDI ARABIA: IMPLICATIONS FOR MANAGING A REMNANT POPULATION

Philip J. Seddon & Yolanda van Heezik

*National Wildlife Research Center, National Commission for Wildlife Conservation and Development, PO Box 1086, Taif, Saudi Arabia*

(Received 1 June 1994; revised version received 18 March 1995; accepted 25 March 1995)

**Abstract**

The Harrat al-Harrah reserve is currently the only area known in Saudi Arabia in which houbara bustards *Chlamydotis undulata macqueenii* may be found all year round, and in which breeding attempts still occur in most years. We examined the feasibility of obtaining estimates of houbara density in Harrat al-Harrah, and documented the pattern of seasonal changes in relative houbara abundance, relating this to abundance of crawling invertebrates and vegetation. Estimated densities of houbara ranged from 0.032 to 0.097/km², which is low compared to estimates from other parts of the houbara’s range. Variations in houbara numbers and flock sizes were not associated with concurrent changes in the availability of food resources. Seasonal changes in houbara abundance may be the result of movements by migrant houbara. Resource availability peaked in spring, when houbara numbers in the reserve were lowest, and when migrants were presumably taking advantage of similar resource peaks in their own breeding areas. These findings imply that encouragement of houbara populations in Harrat al-Harrah requires the protection or management of populations beyond the reserve, and probably even outside Saudi Arabia.

**Keywords:** houbara, bustard, Saudi Arabia, density, resource availability.

**INTRODUCTION**

Current understanding of the distribution and movements of the houbara bustard *Chlamydotis undulata macqueenii* suggests that Saudi Arabia seasonally contains both breeding and migrant birds. Over the last few decades houbara bustard populations, both resident and migrant, have declined. The causes of this decline are likely to include the same factors that have affected houbara populations in other parts of their range, namely, the combined effects of unsustainable hunting, habitat degradation through overgrazing and agricultural development, and the general disturbance of human encroachment (Collar, 1980). Early written accounts of houbara breeding distribution delimit a probable core breeding range in the north of Saudi Arabia (summary in Jennings, 1988, 1989). Migrant houbara are still found in reduced numbers throughout the Kingdom during the winter, but there is currently only one confirmed locality in Saudi Arabia where houbara may be found all year round, the 13,775 km² Harrat al-Harrah protected area (Child & Grainger, 1990), where breeding attempts still occur in most years.

Saudi Arabia’s wildlife conservation authority, the National Commission for Wildlife Conservation and Development (NCWCD), has undertaken to restore houbara bustard populations in Saudi Arabia through captive-breeding and reintroduction, and by protecting wild populations. The programme to encourage the natural increase in wild houbara numbers, resident and migrant, is centred on Harrat al-Harrah. It was assumed that following the removal of most domestic livestock and with protection from hunting, the numbers of houbara within the reserve would increase (Child & Grainger, 1990: appendix II). Until now, seven years after protection, no reliable estimate of houbara density was available with which to assess subsequent houbara population trends. Even qualitative assessment of population trends is difficult due to marked fluctuations in the number of houbara within the reserve. This variation possibly reflects a seasonal overlap between presumed resident breeding houbara and non-breeding migrants (Goriup et al., 1992).

This study was undertaken to investigate the feasibility of obtaining regular estimates of Harrat al-Harrah houbara density, and to document seasonal changes in houbara numbers, and in resource availability. This would allow a clearer understanding of the relative importance of local environmental conditions and extraneous factors in determining houbara numbers in Harrat al-Harrah.

**STUDY AREA**

In 1987 Harrat al-Harrah was declared a Special Natural Reserve by the NCWCD’s Board of Governors. The
area contains significant remnant populations of houbara and sand gazelle *Gazella subgutturosa*, and is a representative portion of a major biotope — the harrat (basalt boulder fields) (Child & Grainger, 1990). Situated in the extreme north-west of Saudi Arabia (Fig. 1), Harrat al-Harrah is the southern portion of a 45,000 km$^2$ harrat which extends from northern Saudi Arabia into Jordan and Syria. The reserve is an undulating plain at about 850 m asl strewn with basalt boulders, aeolian sand and qahs (dry lakes), and dotted with extinct volcanic cones. Trees are virtually absent, and the sparse vegetation is concentrated in broad wadi beds, smaller dry water-courses and on the margins of silty depressions. Mean bimonthly maxima and minima ambient temperatures and rainfall measured at Turaiq, immediately north of the reserve, show that peak temperatures occur in mid-July, and lowest temperatures in January (Fig. 2a). There is usually no rain between May and August; most falls between January and March. Annual rainfall is in the range of 50–100 mm and though seasonally predictable it is unreliable in quantity and distribution. Before protection the area was extensively grazed by domestic livestock. Currently sheep and goats are excluded, but as many as 6000 untended domestic camels graze freely within the reserve’s boundaries. Hunting is forbidden, and the reserve is patrolled daily by light aircraft, and on the ground by rangers based at eight camps throughout the reserve.

**METHODS**


**Density estimation**

Sightings of houbara were recorded by two observers during driven transects of approximately 40 km length within a 700 km$^2$ core study area. Transects were placed in each of five arbitrarily defined non-overlapping survey regions.

In order to distribute search effort more or less equally among the five survey regions in the first season (December 1991–July 1992), we combined all drives made in each region within a period of three days. In the second season (November 1992–October 1993) search effort was equally distributed between each region each month; a sample therefore corresponded to
one transect in one area. Because of low sample sizes (detections) per drive, each transect was driven twice in the space of five days, once or twice per month. Since such data may not be independent, we combined the data and the search effort for analyses. We assumed that transects were placed at random with respect to houbara distribution.

Transsects were driven in the morning or late afternoon, to eliminate potential bias due to decreased houbara activity over the middle of the day (as per Peris et al., 1992). At each sighting we recorded perpendicular distance from the transect route, and flock size. Distances were measured by pacing, driving, or were estimated within categories 0–50 m, 50–100 m, 100–150 m, 150–200 m, 200–300 m, 300–400 m, 400–500 m, 500–600 m, 600–700 m, and 800+ m. Other assumptions (see Franzreb, 1981; Buckland et al., 1993) made were: (1) houbara directly on the transect route were never missed; (2) individuals were not counted twice; (3) sightings were independent events; (4) the response of birds did not vary with sex or age; (5) the probability of observing a bird decreased with distance from the transect.

Estimates of density were obtained by fitting a detection function to the perpendicular distance data. Detection function fitting and density estimation were performed by the program ‘DISTANCE’ (Laake et al., 1993). Data were entered as exact flock sizes, and perpendicular distance as either the exact measure (±10 m) or the mid-point of defined distance intervals.

<table>
<thead>
<tr>
<th>Date</th>
<th>Effort (km)</th>
<th>n</th>
<th>S</th>
<th>Density/km² SE</th>
<th>%CEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>December</td>
<td>500</td>
<td>5</td>
<td>5</td>
<td>0.154</td>
<td>0.182</td>
</tr>
<tr>
<td>1992</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>1749</td>
<td>20</td>
<td>40</td>
<td>0.123</td>
<td>0.036</td>
</tr>
<tr>
<td>February</td>
<td>417</td>
<td>8</td>
<td>13</td>
<td>0.144</td>
<td>0.072</td>
</tr>
<tr>
<td>March</td>
<td>1497</td>
<td>22</td>
<td>34</td>
<td>0.047</td>
<td>0.012</td>
</tr>
<tr>
<td>April</td>
<td>572</td>
<td>6</td>
<td>7</td>
<td>0.020</td>
<td>0.006</td>
</tr>
<tr>
<td>July</td>
<td>578</td>
<td>6</td>
<td>4</td>
<td>0.115</td>
<td>0.065</td>
</tr>
<tr>
<td>November</td>
<td>856</td>
<td>10</td>
<td>12</td>
<td>0.015</td>
<td>0.008</td>
</tr>
<tr>
<td>December</td>
<td>802</td>
<td>10</td>
<td>12</td>
<td>0.051</td>
<td>0.022</td>
</tr>
<tr>
<td>1993</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>803</td>
<td>10</td>
<td>9</td>
<td>0.046</td>
<td>0.023</td>
</tr>
<tr>
<td>February</td>
<td>797</td>
<td>10</td>
<td>5</td>
<td>0.014</td>
<td>0.007</td>
</tr>
<tr>
<td>March</td>
<td>794</td>
<td>10</td>
<td>4</td>
<td>0.008</td>
<td>0.003</td>
</tr>
<tr>
<td>April</td>
<td>399</td>
<td>5</td>
<td>2</td>
<td>0.008</td>
<td>0.005</td>
</tr>
<tr>
<td>July/August</td>
<td>803</td>
<td>10</td>
<td>12</td>
<td>0.063</td>
<td>0.033</td>
</tr>
<tr>
<td>October</td>
<td>780</td>
<td>5</td>
<td>7</td>
<td>0.032</td>
<td>0.014</td>
</tr>
</tbody>
</table>

We found that encounter rates of houbara were so low in some months that it would have been necessary to have driven up to 15,000 km in each month of low abundance to achieve a density estimate with a percentage coefficient of variance (CEV) of about 20% (employing equation 7.1 in Buckland et al., 1993). Since logistical problems of fuel supply and the nature of the terrain precluded such an exercise, we combined months to present an estimate of the mean ‘high’ (monthly densities >0.05) and a ‘low’ (monthly densities <0.05) figure for the duration of the study (see Table 1 for monthly densities).

Flock sizes were recorded between December 1991 and April 1993. Our own observations were supplemented by records from rangers and pilots, covering a five-year period from 1989 to 1993. Results are presented as monthly means and annual variation for all years combined.

Habitat

We recognised seven broad habitat types within the study area: (1) harrat — weathered basalt rock fragments, usually on low hills; (2) chert/gravel — chert/coarse gravels on undulating hills; (3) wadi — major dry watercourse, with a broad bed of sand, gravel or rock fragments; (4) wash — a minor dry watercourse usually draining into a wadi, with a narrow channel receiving seasonal runoff from rocky and raised ground; (5) drainage line — dry runnel delineated by a line of vegetation running between low harrat hills; (6) sand; (7) silty depression — low-lying basin receiving runoff from wash or drainage line. Two sub-types were recognised: (i) qah or annually flooded silty depression — compressed fine silt substratum and only margin vegetation; and (ii) dry silty depression — looser coarser substrate and better drainage and vegetative cover. Houbara are omnivorous, feeding on both plants and crawling invertebrates. In each habitat type
we therefore measured vegetative composition, plant phenology, and seasonal changes in diversity and abundance of invertebrates.

**Vegetation sampling**

In December 1992, between 10 and 15 examples of each of the seven habitats (sand occurred infrequently in the core study and was not sampled) were surveyed and the identity of dominant perennial plants recorded to species level. During each month of the study a sample of each of the seven habitats was visited and the status of the seven main perennials, and of annual plants in general, was recorded as 0 = absent above ground; 1 = dehiscent, but present; 2 = new green growth; 3 = flowering and/or fruiting. For each month, plant phenology codes were combined to provide an index of plant productivity, with values theoretically ranging from 0 (no plants present) to 24 (all plants fruiting/flowering in the same month). Plant nomenclature follows Collenette (1985) and Mandaville (1990).

**Insect sampling**

Examples of each habitat type were sampled for crawling insects at the same time as houbara abundance was recorded in 1992–1993. Pitfall traps containing a small amount of water and detergent were placed flush with the ground. Each habitat was sampled at three independent locations. Traps were collected after five days, and the contents identified to taxonomic group and counted.

**Resource availability**

Six estimates of houbara food resource availability were calculated for all habitat types combined and for each month of the study: invertebrate numbers by taxa (beetles, ants, arachnids), total invertebrate numbers, plant productivity index, and a combined resource availability index obtained by summing the rank of the plant productivity index scores and the rank of the total invertebrates (minimum value 2, maximum 16). We calculated Spearman rank-order correlation coefficients to examine the association between houbara abundance, houbara flock size, and these six measures of resource availability.

**RESULTS**

Seasonal trends were examined by comparing the number of houbara sighted per kilometre driven. Perpendicular distances did not vary with flock size (Kruskal-Wallis test; $H = 13.6$, d.f. = 11, $p > 0.05$, $n = 152$ sightings). A comparison of combined winter and mid-summer values (houbara non-breeding; $n = 40$ sightings) with spring values (houbara breeding; $n = 28$ sightings) showed no difference in perpendicular distances (single birds only, Mann-Whitney $U$ test, $U = 583.5$, $p > 0.05$). We therefore concluded that any seasonal variation in behaviour did not significantly affect the detectability of houbara, so that the pattern of change recorded reflects real changes in abundance of houbara within the study area.

**Fig. 3.** Seasonal changes in abundance of houbara during two years; means and standard errors; $n$ = number of survey drives, given above error bars.

**Densities and flock sizes**

The estimated mean 'high' density of houbara from two years of surveys was 0.097/km² (SE = 0.021; effort = 3272 km; $n = 74$ encounters; %CEV = 22%), and the mean 'low' density was 0.032 km² (SE = 0.005; effort = 6851 km; $n = 92$ encounters; %CEV = 17%). Monthly estimates, variation around the mean (SE) and a measure of their precision (%CEV) are given in Table 1 (July and August 1993 are lumped to reduce variation). Seasonal patterns in numbers of houbara sighted per km driven (Fig. 3) showed significant variation throughout both seasons (Kruskal-Wallis test; 1991–92, $H = 15.11$, $k = 5$, $p < 0.01$, 1992–93, $H = 37.30$, $k = 7$, $p < 0.001$). Numbers were relatively high during summer and winter, and decreased in spring. Patterns of change were similar in both seasons.

**Fig. 4.** Annual change in houbara flock size; means and standard errors; $n$ = number of flocks sighted; all years combined.
Flock sizes (overall mean = 5.3, SD = 3.6, n = 49) followed a similar pattern, increasing in winter and summer, and decreasing in autumn and spring (ANOVA $F = 6.38$, d.f. = 11, 716, $p < 0.001$; Fig. 4). Flocks ranged in size from two to 20 individuals. Lone birds accounted for 33% of all observations, with flocks of two to five birds making up 44% of sightings.

**Habitat characteristics and seasonal changes**

**Vegetation composition**

In well-vegetated areas such as wadis and washes, three assemblages commonly occurred, dominated by *Artemisia sieberi* or *Achillea fragrantissima* on packed clay substrates, and *Haloxylon salicornicum* with *Artemisia monosperma* common on loose sandy substrates. The edges of annually flooded silty depressions were dominated by shrubs of *A. sieberi*, *A. fragrantissima*, *Capparis spinosa* and *Zilla spinosa*. Although dry silty depressions were less hard-packed, vegetation was usually concentrated around the edges; dominant shrubs were *A. sieberi*, *H. salicornicum*, *Z. spinosa*, with *Astragalus spinosus* and *A. fragrantissima* occurring occasionally. Drainage lines were always dominated by *A. sieberi*, with occasional *H. salicornicum*, *A. spinosus* and *Z. spinosa* shrubs. Gravel plains and harrat were almost bare of vegetation in winter. Given adequate rainfall during winter, all of these habitats support a variety of annuals.

**Vegetation phenology**

Plants of *Z. spinosa*, *A. fragrantissima*, *A. spinosus* and *A. sieberi* began new growth in spring and flowered between spring and early summer. *H. salicornicum*, *A. monosperma*, and *C. spinosa* produced green shoots in spring and summer, and flowered/fruiting usually in summer, sometimes as late as late autumn. The amount of new growth, and the timing of its onset, depended on local patterns of rainfall and was quite variable. Annuals generally appeared in November, in response to rainfall, reached their peak in spring (April/May), and in areas that had received late rainfall were occasionally observed as late as early summer (May/June). The index of plant productivity ranged from a minimum of 9 in the cold months of January and February to a maximum of 18 coinciding with the spring flush in May (Fig. 2b).

**Invertebrate abundance and seasonal changes**

Well-vegetated habitats such as wadis and washes contained a greater abundance of Coleoptera, particularly Tenebrionidae (eight of the 10 species identified), than the moderately vegetated silty depressions and drainage lines, and the poorly vegetated harrat and gravel plains ($F = 3.52$, d.f. = 2, 85, $p = 0.034$), but overall species diversity did not differ significantly between these categories ($F = 2.16$, d.f. = 2, 85, $p = 0.087$). Diversity of Formicidae varied across habitats ($F = 3.08$, d.f. = 2, 85, $p = 0.051$), but abundance did not vary significantly ($F = 0.84$, d.f. = 2, 85, $p > 0.05$). Abundance and diversity of Arachnida, almost entirely spiders, were greatest in moderately vegetated habitats ($F = 21.38$, d.f. = 2, $p < 0.001$; $F = 15.62$, d.f. = 2, $p < 0.001$, respectively).

Combining all habitats, abundance of invertebrates and species diversity showed significant intra-annual variation ($F = 7.21$, d.f. = 7, 80, $p < 0.001$; $F = 13.21$, d.f. = 7, 80, $p < 0.001$, respectively), with a large increase in numbers in April (spring), followed by a decrease throughout summer and autumn (Fig. 5). Coleoptera abundance and diversity (number of taxonomic groups) peaked in the hotter months of April and July ($F = 13.04$, d.f. = 7, 80, $p < 0.001$; $F = 12.37$, d.f. = 7, 80, $p < 0.001$, respectively), whereas arachnid abundance and diversity peaked in November and December (Kruskal-Wallis; $H = 22.8$, d.f. = 7, $p < 0.01$; $H = 19.5$, d.f. = 7, $p < 0.01$). Ant abundance showed two peaks, in April and in October ($F = 4.295$, d.f. = 7, 80, $p < 0.001$), whereas diversity fluctuated throughout the year ($F = 2.44$, d.f. = 7, 80, $p < 0.025$). There was a significant association between numbers of

---

**Fig. 5.** Annual variation in invertebrate abundance (■) and number of species (●) in Harrat al-Harrah; bars represent standard errors; n = 10 habitat types sampled (see text; wadis further subdivided into *A. sieberi*-, *A. fragrantissima*-, or *H. salicornicum*-dominated, or mixed).
invertebrates trapped and mean maximum tempera-
tures during the trapping period (Spearman rank-order
correlation, \( r_s = 0.810, n = 8, p < 0.05 \)), but no asso-
ciation between invertebrate species diversity and mean
maximum temperatures (\( r_s = 0.333, n = 8, p > 0.05 \)).
Invertebrate abundance increased sharply in April,
when temperatures first rose above 10°C (minimum)
and 25°C (maximum). The index of resource availabil-
ity ranged from a high of 16 in April, to a low of 3 in
January (Fig. 2b).

One-tailed Spearman rank-order correlation testing
with the alternative hypothesis that houbara numbers
were positively associated with resource availability did
not reveal significant correlations for any of the six
resource measures (\( n = 8, p > 0.05 \)): beetle numbers
(\( r_s = -0.28 \)); ant numbers (\( r_s = -0.36 \)); arachnid numbers
(\( r_s = 0.19 \)); total invertebrate numbers (\( r_s = -0.38 \));
plant productivity (\( r_s = -0.69 \)); resource availability index
(\( r_s = -0.57 \)). The large negative correlation between
houbara numbers and plant productivity approached
significance at the 5% level for a two-tailed test. There
was no significant association between houbara num-
bers and rainfall measured in the same month (\( n = 12, \)
\( r_s = 0.39 \)).

Flock size was also not significantly correlated to any
measure of resource availability, but there was a signifi-
cant positive association between flock size and houbara
numbers (\( n = 8, r_s = 0.8, p < 0.025 \), one-tailed).

**DISCUSSION**

**Patterns of houbara abundance**

Annual patterns of houbara abundance were similar
over both field seasons: relatively high numbers
between December and January, a decrease between
February and April, followed by an increase in July.
The observed low numbers in spring are most easily
explained as the result of an outflux of overwintering
migrant houbara, returning to their summer breeding
grounds. Observations of houbara densities, flock
movements, and departure and arrival times to various
regions suggest that populations of *C. u. macqueenii*
that breed in Kazakhstan and surrounding districts are
migratory (Dementiev & Gladkov, 1951), wintering in
southern parts of Soviet Central Asia, Pakistan (Malik,
1985; Shams, 1985) and adjacent parts of north-west
India (Surahio, 1985), southern Iran (Mansoori, 1985)
and north-eastern parts of Arabia. While some birds
may overwinter in the former Soviet Union, most
appear to move south from mid-September, with large-
scale departures throughout September and October
(Dementiev & Gladkov, 1951). By November migrants
are believed to be in their winter quarters (Mansoori,
1985). Migrants reappear in breeding grounds between
early March and early April (Dementiev & Gladkov,
1951; Alekseev, 1985). It is also possible that move-
ments of houbara from small populations that exist in
Syria, Iraq, or Oman may contribute to the variation in
numbers we observed in Harrat al-Harrah in winter.
Currently the only evidence for such movements is the
recovery in Syria of a single houbara banded in Harrat
al-Harrah (P. Gorup, Pers. comm.).

Increased numbers of birds in July may also occur if
early-failing breeders from other regions enter Harrat
al-Harrah at this time to exploit mid-summer peaks in
insects and fruiting perennials. Houbara are highly
mobile, and may also move into the reserve from other
parts of Saudi Arabia. Additionally, offspring from
breeding in March may boost numbers, although
breeding attempts in Harrat al-Harrah appear to be too
few to account for such an increase. The winter increase
in numbers of houbara in Harrat al-Harrah corresponds
with the start of the rainy period, the subsequent
growth of green annuals and highest density of spiders.
In spring (when houbara breeding occurs) most annuals
flower and set seed, providing abundant food. Ants, which
are an important source of food for houbara (Slaytor,
1989; Gaucher, 1991; Gorup et al., 1992) also increase
substantially towards the end of spring. In summer,
abundance of these invertebrates remains high and several
species of perennial shrubs produce flowers and fruit.

Flock size variation probably depends more on patch
richness, rather than accurately reflecting variation in
absolute population size. Flock sizes in the Negev
tended to be larger in areas with ample food supply,
with the largest flocks being seen at garbage dumps (up
to 60 birds) (Mendelsohn, 1980), or in ploughed fields
(up to 43 birds) (Lavee, 1985). In Sind, flocks formed to
exploit patches of fresh green plants and dispersed
when these dried up (Surahio, 1985). From December
until February in Harrat al-Harrah new green growth
occurred in some wadis, in response to rainfall, providing
a resource exploitable by larger groups. In summer, hou-
 bara foraging was frequently concentrated on small patches of
*Capparis spinosa*, which becomes green and produces
succulent fruits in the middle of the hot dry period.

Although our data do not explain the seasonal varia-
tion in houbara numbers the following possibilities can
be suggested. Peak resource availability occurs in
spring, a time at which migrants have left the reserve
and are presumably enjoying similar conditions on
their own breeding grounds. Timing of arrival of
migrants in Harrat al-Harrah may therefore depend on
conditions en route or otherwise outside the reserve.
Houbara may use Harrat al-Harrah in summer to
exploit the relatively large number of flowering peren-
nials not available in the surrounding overgrazed areas,
but if the autumn rains are good there will be a flush of
annuals over large parts of Saudi Arabia and houbara
can disperse. The mid-winter peak in numbers may
reflect movement back into the protected area, to avoid
hunting in other regions. In Saudi Arabia hunting of
houbara is restricted by law to between December and
February each year.

**Density of houbara**

The absence of earlier estimates of houbara density
in Harrat al-Harrah prevents any assessment of pop-
ulation trends since reserve creation in 1987. Within the
limits of precision obtained in this study the total
Options for houbara management

(1) Reduce disturbance within Harrat al-Harrah by more rigorously excluding human intruders, and by limiting camel numbers. This would have the additional benefit of reducing grazing pressure and enhancing vegetation, and may be the most simple and immediate trial management to improve conditions for houbara.

(2) Enforce existing hunting laws in Saudi Arabia more rigorously, to reduce hunting pressure on houbara moving outside the reserve’s borders.

(3) Take an active role in the protection and enhancement of houbara populations in breeding areas contributing to Saudi Arabia’s migrant houbara population. These are not known at present but could include Syria, Iraq, or even areas within the Commonwealth of Independent States. These measures could include: (i) a decrease in hunting pressure; (ii) encouragement for the protection of breeding areas, to prevent disturbance from human activity and the degradation or loss of houbara habitat.

Repeat estimates of populations, using standardised methods, will be needed to ascertain the effectiveness of such management practices on long-term trends.

ACKNOWLEDGEMENTS

We thank His Royal Highness Prince Saud Al Faisal, the General Manager, and Dr Abdulaziz H. Abuzinada, the Secretary General of the National Commission for Wildlife Conservation and Development, for their support of this work. Much appreciated assistance in the field was given by Hans Hemmingssen (Chief Pilot) and other members of the NCWCD flight crew; and by Ali Hamad Al Murri (Head Ranger), Fahd Hamad Al Murri (Deputy Head Ranger) and their ranger staff. Peter Symens organised an houbara sightings recording scheme for rangers, from which came some of the flock size data. Sheila Colenette identified much of the vegetation and Frédérique Rambaud did likewise for the invertebrates. We thank staff from the NWRC for support in the field. The manuscript was improved by the comments of Brian Davis and two anonymous referees.

REFERENCES


