

Reintroduction of the Arabian oryx *Oryx leucoryx* in Jordan: war and redemption

Lee E. Harding, Omar F. Abu-Eid, Nashat Hamidan and Ahmad al Sha'lan

Abstract Following the extinction of the Arabian oryx *Oryx leucoryx* in the wild in 1972 Jordan began a reintroduction programme in 1978 with 11 founding animals. When the herd size reached 31 in 1983 most were released from captive breeding pens into the 342 km² Shaumari Nature Reserve, part of which (22 km²) was fenced the following year to protect the oryx and exclude livestock. The herd grew initially (between 1979 and 1986) at about 23% per year. In 1990, when the herd numbered 79, its management was preparing to release it into the wild outside the fenced reserve. However, Bedouin families fleeing the Gulf War in Kuwait and Iraq brought 1.6 million sheep, goats, camels, and donkeys into Jordan. These livestock so overgrazed potential oryx habitat throughout the arid rangelands that reintroduction was impossible. Over-

crowding within Shaumari became apparent by 1995, when the population numbered 186. The herd's rate of increase began to decline as productivity and recruitment decreased and mortality increased. In 1997, to reduce overcrowding, the herd's management began dispersing them to other Middle Eastern countries and to another nature reserve in Jordan. By February 2006, 43 oryx remained at Shaumari. In 2005, however, the prospects improved when the United Nations Compensation Commission awarded Jordan the cost of environmental damages resulting from the 1990-1991 Gulf War. Part of this award is designated for renewal of the captive breeding and reintroduction programme.

Keywords Captive breeding, desert, *Gazella subgutturosa*, Gulf war, Jordan, *Oryx leucoryx*, rangeland, reintroduction.

Introduction

The Arabian oryx *Oryx leucoryx* originally occurred in Jordan, Syria, Iraq, Israel, Sinai and the Arabian Peninsula, but was extirpated from the wild in 1972 (Henderson, 1974). It has been on CITES Appendix I (CITES, 2007) since 1975 and is categorized as Endangered on the IUCN Red List (IUCN, 2006). Currently there are five reintroduced populations in large areas of natural habitat, although all have some degree of protection: Oman (Arabian Oryx Sanctuary, 27,500 km²); Saudi Arabia (Mahazat as-Sayd Reserve, 2,244 km², and Uruq Bani Ma'arid Reserve, 12,500 km²); and Israel (Northern Arava and Negev Desert; Jungius, 1978; Clark, 1987;

Abu-Jafar & Hays-Shahin, 1988; Ostrowski *et al.*, 1998; Bedin & Ostrowski, 2003).

In Jordan oryx originally occurred throughout the northern steppe grasslands and eastern desert (the *badia*). They were hunted intensively after 1932, when the construction of the Baghdad-Haifa oil pipeline was accompanied by 'massive mechanized shooting' of oryx (Quemsiyeh *et al.*, 1996). Some oryx were also killed by pesticides applied across wide areas of the *badia* to control locusts in the 1950s (Hatough & Al-Eisawi, 1988). The last wild oryx in Jordan was shot in the early 1960s near Qatranah, c. 75 km south of Amman (Mountfort, 1965).

In 1978 the Royal Society for the Conservation of Nature in Jordan (RSCN, an NGO) began an oryx reintroduction programme. It obtained 11 oryx from the San Diego Wild Animal Park in the United States (four males and four females) and the Royal herd in Qatar (one male and two females; Table 1). In 1984 the Zurich Zoo in Switzerland provided three males. The founders were from two separate bloodlines: those from San Diego and Zurich were of Yemeni-Saudi stock, whereas those from Qatar were considered a separate stock. They were placed in a captive breeding enclosure consisting of pens and a fenced compound occupying a small portion of the 342 km² Shaumari Nature Reserve in eastern Jordan (Fig. 1).

Lee E. Harding (Corresponding author) SciWrite Environmental Sciences Ltd, 2339 Sumpter Drive, Coquitlam, British Columbia, Canada, V3J 6Y3. E-mail harding@SciWrite.ca

Omar F. Abu-Eid Delegation of the European Union to the Hashemite Kingdom of Jordan, P.O. Box 926794, Amman 11110, Jordan.

Nashat Hamidan Royal Society for the Conservation of Nature, P.O. Box 1215, Amman 11941, Jordan.

Ahmad al Sha'lan Royal Society for the Conservation of Nature, Shaumari Nature Reserve, Jordan.

Received 5 May 2006. Revision requested 11 August 2006.
Accepted 14 November 2006.

Table 1 Provenance or disposition of Arabian oryx imported or exported from the Shaumari Nature Reserve.

	Year	Females	Males	To/from
Imported	1978	4	4	USA
	1979	2	1	Qatar
	1984		3	Switzerland
<i>Total imported</i>		6	8	
Exported	1984	1		Oman
	1987	2	2	Oman
	1987		1	Iraq
	1989	1	2	Saudi Arabia
	1997	4	4	Syria
	2000	20	12	Qatar
	2000	14	11	United Arab Emirates
	2000	7	5	Saudi Arabia
	2001	4	4	Saudi Arabia
	2002	2	2	United Arab Emirates
	2002	3	7	Wadi Rum, Jordan
	2006	4	2	Wadi Rum, Jordan
	<i>Total exported</i>		62	52

In 1983 the RSCN began releasing oryx out of the captive breeding enclosure into the whole Reserve, shared with other large grazers and occasional predators. This was considered a reintroduction into the wild because the reserve outside the captive breeding enclosure is native habitat in a natural state and the herd was managed with minimal human interference (Bauman, 1979; Abu-Jafar & Hays-Shahin, 1988; Hatough & Al-Eisawi, 1988). Oryx are nomadic, however, ranging over a large area while using a series of separate, suitable areas mostly 100–300 km² in size for 1–18 months at a time (Price, 1986), typically with a mean herd size of 5.8, some solitary bulls and a bachelor herd (Spalton, 1993). The situation at Shaumari was therefore transitional to a truly wild, free-ranging population, which the RSCN planned to establish eventually (Mountfort, 1969; Clarke, 1977, 1979).

Our purpose here is to document the demography of this population from its early, rapid expansion through eventual decline to provide a foundation for further reintroductions within and outside of Jordan.

Study area

The Shaumari Nature Reserve is in arid desert with temperatures frequently above 42°C in summer and down to -10°C in winter. Rain only falls in winter and averaged 62.2 mm per year (range 10.1–149.0) from 1967 to 1997 at nearby Azraq (Government of Jordan, unpubl. data). The habitat is *hammada*, a flat, treeless terrain covered by flint or limestone pebbles, with many wadis. Wadi vegetation may contain shrubs up to 2 m tall and small trees (e.g. *Tamarix* spp.), whereas *hammada* is virtually barren except for sparse forbs and grasses that

flourish briefly following rainfall. In 1984, 22 km² of the Shaumari Nature Reserve was completely fenced to exclude livestock and to contain the oryx and other large wildlife, which include Persian onagers *Equus hemionus onager*, goitered gazelles *Gazella subgutturosa*, and blue-necked ostriches *Struthio camelus austrellus*. By the mid 1980s this protection from grazing had allowed the development of a structurally complex and species-rich plant community that supported a more diverse community of mammals, reptiles and birds than outside the reserve (Al-Eisawi & Hatough, 1987; Hatough-Bouran & Al-Eisawi, 1990). Water is provided from a well and mature tamarix and planted eucalyptus trees provide shade.

Methods

Population data

We examined the oryx log (a record of every oryx born at the Reserve) for internal consistency and compared it with independent reports of the population at Shaumari. Finding that a few of the records prior to 1995 were incomplete, we made the following adjustments: (1) For five of 87 (6%) death records prior to 2000, the year of death was missing. To approximate these five death dates we used either the median age of death for that cohort or the date of last observation. (2) Eight of 403 (0.02%) births for which the sex of a calf was not recorded, or was recorded as unknown, were omitted from the population calculations on the assumption that they died before their first year (in all such cases there was no further mention of those individuals).

Another inconsistency in the oryx log was the number of calves born compared to published reports. For example, a visiting ornithologist mentioned that 18 oryx calves had been born at Shaumari by the end of 1981 (Conder, 1981) but the oryx log lists only nine up to that date. Budieri (1995) reported that 328 calves had been born, although the oryx log only listed 272 by the end of 1995. Presumably, some calves were not entered into the log because they died as neonates and the staff at Shaumari felt they had not been recruited to the population and therefore should not be recorded.

Analysis

We reorganized the oryx log data to list the founding population, number of new male and female calves born, number of male and female calf deaths, and number of male and female yearling and adult deaths, by year. Yearling recruitment was calculated as the number of the previous year's female and male calves minus the previous year's male calf and female calf deaths, per 100 adult females. Each year's population of yearlings and adults was therefore the previous year's

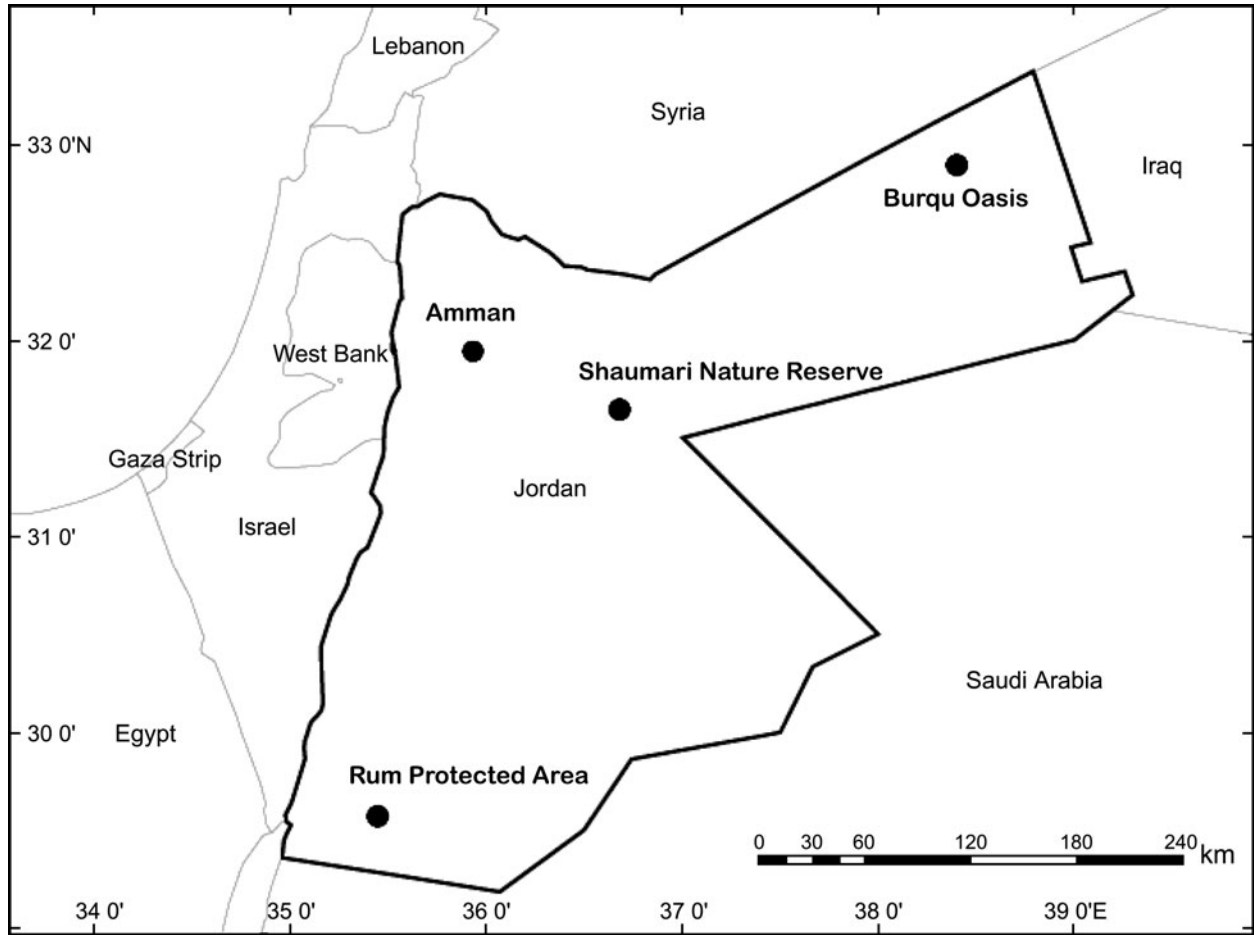


Fig. 1 Jordan, with the location of the Shaumari Nature Reserve, the Rum Protected Area, and the proposed nature reserve at Burqu.

yearling and adult males and females plus the number of male and female yearlings recruited, plus the new acquisitions, minus the number of male and female yearling and adult deaths, and minus the dispersal of adult oryx to other locations. The total population (N) was these plus the number of calves surviving at the end of the year. We calculated the annual increase in the population, lambda (λ), using the exponential model given by

$$\lambda = \left(\frac{N_t}{N_0} \right)^{\frac{1}{t}}$$

where N_0 = initial population size, N_t = population at time t , and t = years.

To represent the population increase when density-dependent effects became apparent we used a generalized logistic model (Verhulst, 1838) in which the rate of increase is a function of the population size relative to the maximum population as given by

$$N_{t+1} = N_t + R_0 \left[1 - \left(\frac{N_t}{K} \right) \right]$$

where N_t = population at time t , N_{t+1} = population size at the end of the next interval (year), R_0 = the initial, discrete rate of population growth, and K = maximum population (assumed to be equivalent to carrying capacity).

To express annual population growth in terms of population size, we used the per capita growth rate, or instantaneous rate of increase, r , for continuously increasing populations because of the non-seasonal breeding of oryx

$$r = (N_{t+1} - N_t) / N_t$$

We tested for the Allee effect (Courchamp *et al.*, 1999) or other hormesis relationships (a U-shaped trend line indicating a reversal of the dependent variable with continued increase of an independent variable) with quadratic models (*cf.* Treydte *et al.*, 2001). All curve estimations and statistical analyses were performed with SPSS (Chicago, USA).

Results

Population growth

The oryx log records 454 births and 166 deaths at Shaumari. During 1984–1989 four females and five males from Shaumari were sent to captive breeding centres in Oman, Saudi Arabia, and Iraq (Table 1). In 1990 there were 69 adult oryx at Shaumari but deteriorating range conditions outside the wildlife refuge prevented further reintroductions. By 1996 the oryx log recorded 273 births at Shaumari and the adult population was 206. In 1997, to reduce overcrowding, the RSCN began dispersing oryx to other countries and to a newly created nature reserve in Jordan, the Wadi Rum Protected Area (Abu-Eid, 2001; Table 1).

By autumn 2003 six adults had survived at Wadi Rum, the other four having died, probably of old age. A female calf born at Wadi Rum also did not survive, and may have succumbed to a snakebite. After initially keeping them in a large, fenced enclosure, they were released into the wild. However, when the entire herd wandered south and were about to cross into Saudi Arabia they were captured and returned to the enclosure. From 2003 to 2005 another five died, leaving one old male at Wadi Rum. In February 2006 the RSCN transferred five more oryx to Wadi Rum. We saw all six there in March 2006.

Growth rates

The oryx population grew initially (1979 to 1986) at $R_0 = 23\%$ per year ($\lambda = 1.2336$) inside the Reserve (Fig. 2). Thereafter, they apparently began to suffer density-dependent effects indicated by increasing aggression among males (Budieri, 1995) and a declining rate of increase commensurate with decreasing productivity

and increasing mortality. The per capita growth rate declined linearly with increasing population ($r^2 = 0.283$, $F = 10.3$, $P = 0.004$). When the analysis was limited to 1984–2005 (after most of the herd was released into the reserve from the captive breeding pens) the relationship weakened, but was still statistically significant ($r^2 = 0.232$, $F = 6.1$, $P = 0.023$; Fig. 3). The quadratic model did not show a decrease at low populations, as would have been consistent, for example, with an Allee or other negative founder effect.

Reproduction and recruitment

Although the overall calf sex ratio was 0.91 male per female, there was no significant difference (paired t test, $P > 0.05$) in the numbers of female and male births per year. They were highly correlated ($P < 0.001$), with both genders increasing as the population rose until 1995, and then declining (Fig. 4). The possibility of some births and neonatal mortality not having been recorded may mean that birth rates were underestimated. The regression for number of calves over time fits a quadratic equation ($r^2 = 0.471$, $F = 10.7$, $P < 0.001$), confirming the obvious rise and then fall in the number of births per year. After 1983, when the oryx were released from the captive breeding facility into the Reserve, the birth rate (b , the number of births during the time period, t , divided by the total number of mature females) generally declined as population (N) increased. The trend was close to statistical significance ($P = 0.055$; Fig. 5).

Recruitment of yearlings (male and female calves that survived their first year) increased rapidly until 1983, reaching a maximum of 61.5 yearlings per 100 adult females. From 1984 onwards, after most oryx had been released from the captive breeding facility into the Reserve, recruitment declined (quadratic model, $r^2 = 0.529$,

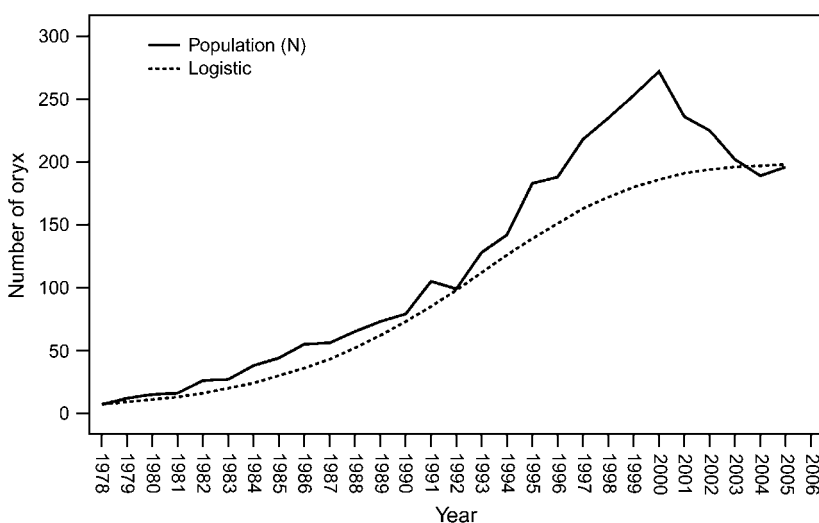


Fig. 2 Oryx population (N) at Shaumari Nature Reserve, Jordan, 1978–2005. The logistic model had an initial growth rate (R_0) of 23% as observed at Shaumari and an assumed maximum population (K) of 200. The sharp decline after 2000 reflects (a) floods that killed 69 oryx in 2000 and 48 in 2002, and (b) a planned dispersal of 119 adult oryx to other Gulf countries and 10 to another nature reserve in Jordan.

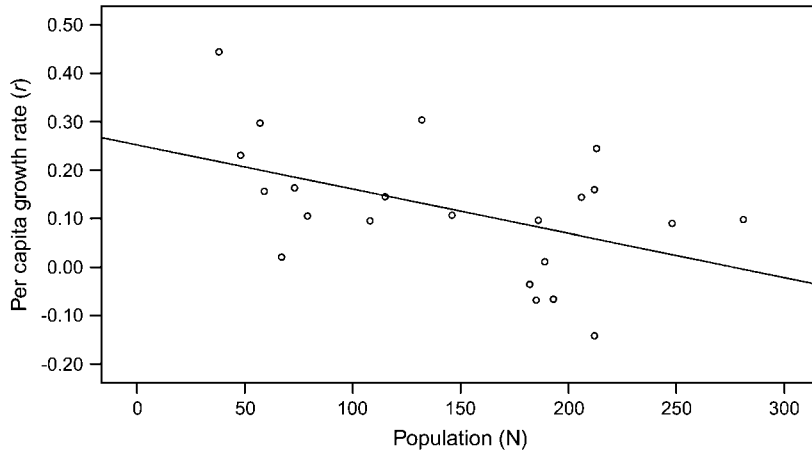


Fig. 3 Annual per capita growth rate (r) in relationship to population for the oryx in Shaumari Nature Reserve, Jordan, 1984-2005, the period after most of the herd was released from the captive breeding pens. The linear trend line is statistically significant at $P \leq 0.05$.

$F = 10.7$, $P = 0.001$; Fig. 6). There was no difference in recruitment of males and females per year (paired t test, $P > 0.05$) and the two were highly correlated ($P < 0.001$). Neither the birth rates (b) nor annual recruitment were related to rainfall ($P > 0.05$), a major correlate of forage availability and hence of ungulate productivity in Middle Eastern deserts (Orshan, 1986). Above average rainfall occurred in 1981, 1983, 1988-1991 and 1995; otherwise, rainfall was less than the long term average.

Survival and mortality

Calf survival, although often above 90%, occasionally dropped to $< 80\%$, in addition to 2 catastrophic years, 2000 and 2002, when floods killed 100 and 92% of calves, respectively (Fig. 7). Male and female calf survival (and, conversely, mortality) were not statistically different ($P > 0.05$). The possibility of some births and neonatal mortality not having been recorded, as noted above, may mean that calf survival was overestimated. Yearling and adult survival was 93-100% for females and 75-100% for males (Fig. 7). Yearling and adult mortality did not change over time ($P > 0.05$) and was not correlated with

population size ($P > 0.05$). The numbers of yearling and adult female and male deaths (and, conversely, survival) were not statistically different ($P > 0.05$).

The leading mortality factor was predation, accounting for 15% of deaths (Fig. 8). Syrian jackals *Canis aureus syriaca*, Arabian wolves *Canis lupus arabs*, red foxes *Vulpes vulpes*, Rueppell's sand foxes *Vulpes rueppelli*, caracals *Caracal caracal*, sand cats *Felis margarita*, wild cats *Felis silvestris tristrami*, and Syrian striped hyaenas *Hyaena hyaena syriaca* occur in the area (Bunaian *et al.*, 2001). Caracals, which could easily kill a young oryx, were seen within Shaumari several times during the late 1990s, coincident with a period of high neonatal mortality, and in 2002.

Floods, although infrequent, were the second highest cause of death in the oryx at Shaumari. Flash floods combined with cold weather were responsible for most of the 19 deaths in 2000 and 30 in 2002. It also is possible that some oryx escaped during floods, as did seven gazelles during a flood in 1994 that damaged the fence. If so, it could account for the five oryx whose death dates were not recorded (i.e. these five oryx either died in the reserve and were not found, or escaped along

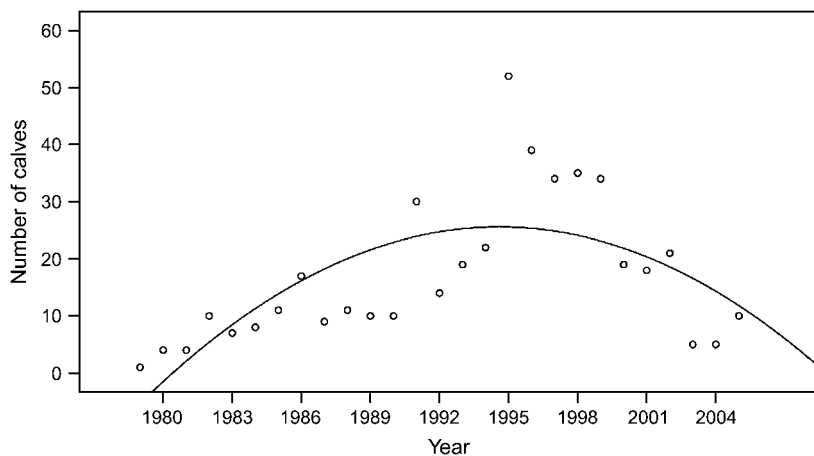


Fig. 4 Annual number of calves born per year at Shaumari Nature Reserve, Jordan, 1979-2005. The fitted line is a statistically significant quadratic model.

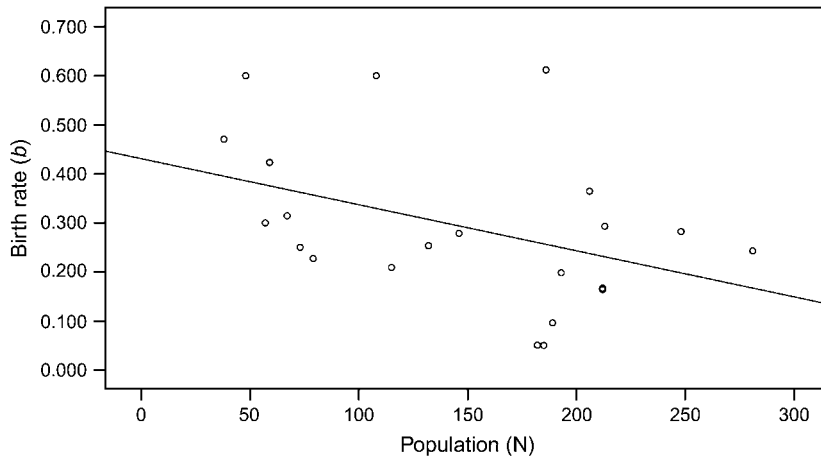


Fig. 5 Annual birth rate (b) in relation to the oryx population at Shaumari Nature Reserve, Jordan, 1984–2005, the period after they were released from the captive breeding facility into the Reserve. The linear regression approaches statistical significance at the 5% level.

with the gazelles). Any oryx that escaped would probably not have survived, not only because of the lack of forage, shade and water, but also because of the dispersed population of Bedouins who undoubtedly would have hunted them.

Diseases (including food poisoning, intestinal parasites, and infections) were the third highest mortality factor. Until 1993, veterinarians provided monthly medical care, performed pathological examinations on deceased individuals, and treated accidentally injured oryx. Serological analysis was carried out for possible carriers of antibodies to major zoonotic diseases such as bluetongue, brucellosis, and *Pasteurellosis*. Faecal samples were taken regularly to check for parasites. After 1993 veterinary care became less regular. Diseases and parasite infestations are likely to have been responsible for some of the deaths from undetermined causes. If this was the case then diseases may have been the highest or second highest source of mortality.

Poisonous snakes killed 2–3 oryx per year (8% of the total mortality) and this factor seemed to the herd's management to be associated with plant cover that provided hiding places for snakes (Budieri, 1995). Hatough *et al.*

(1986) also reported that high reptile diversity was associated with increasing plant cover following protection from grazing at Shaumari. Other causes of death included cold intolerance (7%), birth difficulties (7%), intraspecific aggression (males fighting, 6%), old age and weakness (6%), infanticide (males goring neonates with their horns, 5%), anaesthesia during veterinary procedures (3%), and accidents resulting in bone fractures (2%). The herd's management at Shaumari attempted to reduce infanticide by isolating females with calves from the rest of the herd.

Life span

Males and females lived for up to 18 and 16 years, respectively. Of those that survived their first year, mean life span was $6.9 \pm \text{SD } 4.5$ years for males, $8.8 \pm \text{SD } 4.8$ years for females and $7.7 \pm \text{SD } 4.7$ years for both (Fig. 9).

Discussion

This study shows the value of setting up a good record-keeping system at the outset of captive breeding and reintroduction programmes, and then ensuring continuity

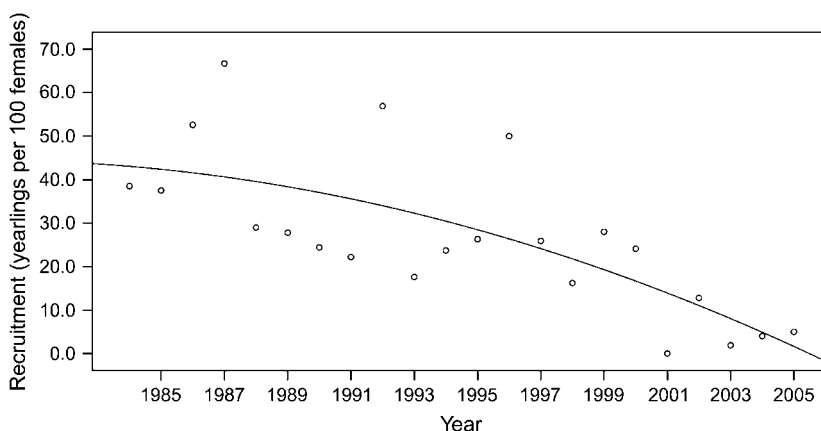


Fig. 6 Recruitment (calves that survived their first year) per 100 adult oryx females for 1984–2005, the period after the oryx were released from the captive breeding facility into the Shaumari Nature Reserve, Jordan. The fitted quadratic line is statistically significant.

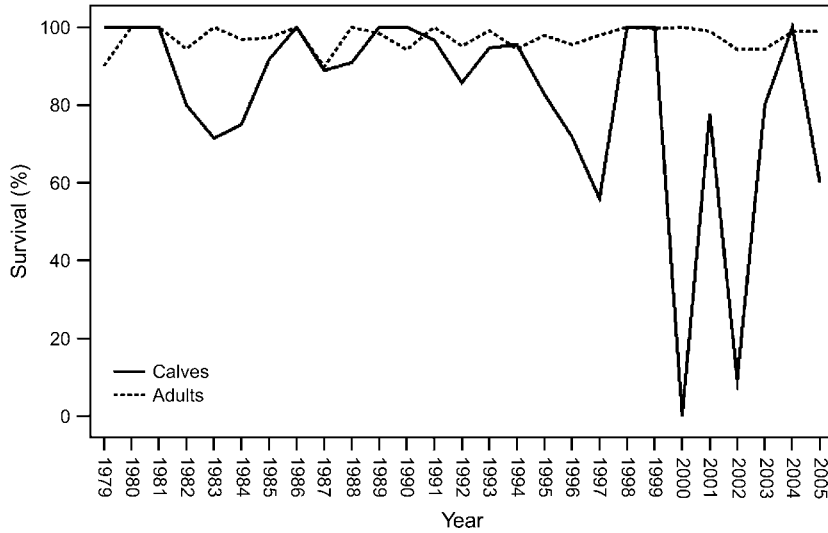


Fig. 7 Annual survival of calves and adults + yearlings at Shaumari Nature Reserve in Jordan, 1979–2005.

and standardization to facilitate retrospective analyses. The initial growth rate (R_0) observed at Shaumari, about 23% per year ($\lambda = 1.2336$), was similar to those of other reintroduced oryx populations. In 1990, 72 Arabian oryx were reintroduced into a 2,244 km² wildlife reserve in Saudi Arabia and increased to 350 by 1998 (Seddon *et al.*, 2003), an annual rate of 22% ($\lambda = 1.22$). After 1998, however, the annual growth rate there declined to *c.* 15% per year ($\lambda = 1.15$). In Oman 35 oryx introduced from 1982 to 1989 increased to 100 in 1990 and 450 in 1996 (Spalton *et al.*, 1999); the 1990–1996 annual growth rate was 28% ($\lambda = 1.28$). On the other hand, an oryx herd reintroduced into a small reserve in Israel experienced a rate of increase of only 7.7% from 1978 to 2003 (Saltz, 1998; EPAA, 2003).

These data (the overall population trend, declining per capita birth rate, increasing mortality, declining recruitment at Shaumari) show a classic example of a population approaching and exceeding the carrying capacity of a small nature reserve. It is not certain, however, whether the carrying capacity was a function of the habitat quality or intrinsic density-dependent population controls, such as male aggression to each other and to calves, both of which were sources of mortality. The sharp drop in productivity after 1995 was reportedly in response to deteriorating browse availability within the Reserve (Boef, 1996; Budieri, 1995). Although no quantitative measurements were made after 1990 this decline is consistent with the carrying capacity estimate of about 180 oryx (Hatough & Al-Eisawi, 1988) based on the abundant vegetation and forage in 1986 (Al-Eisawi & Hatough, 1987). Probably both extrinsic and intrinsic factors were involved. The inconsistent availability of professional wildlife expertise in several areas was another factor resulting in poor productivity in the early 1990s, not only of oryx, but of other species held at Shaumari (Budieri, 1995).

The gazelle population, for example, began with a founding population of 11 in 1980, increased by 12% per year to a high of 34 in 1990, and then declined to 14 in 1994 (L. Harding, unpubl. data). By 2003, the gazelle population had decreased to two, both males. Because their decline preceded that of the oryx by 5 years, it was probably not caused by a lack of forage that would have affected both species simultaneously. Floristic surveys in 1990 showed the vegetation to be abundant, diverse, and well developed structurally (Hatough-Bouran & Al-Eisawi, 1990). However, the herd's manager at the time thought that the gazelles failed to reproduce at higher densities because of improperly designed captive breeding pens, behaviour unsuited to captivity in pens, and high rates

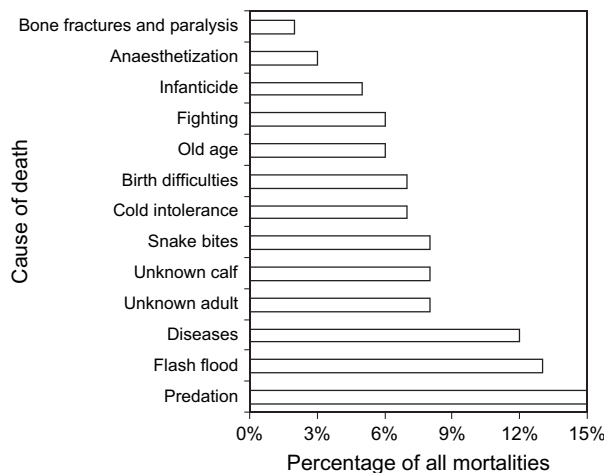


Fig. 8 Frequency of mortality factors for the oryx at Shaumari Nature Reserve, Jordan, 1979–2005.

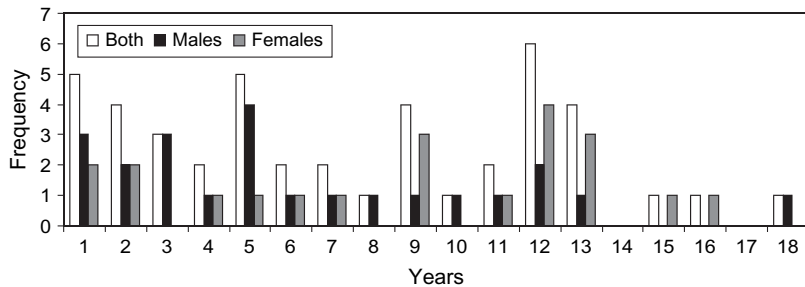


Fig. 9 Frequency distribution of life span of oryx at Shaumari Nature Reserve, Jordan, 1979–2000.

of mortality from diseases brought in by domestic livestock (Budieri, 1995). Sheep and goats are not allowed into the Reserve but commonly graze at its edge and occasionally get inside.

A small flock (c. 20 individuals) of ostriches is maintained at Shaumari. Ostriches feed on green annual grasses and forbs when available, otherwise leaves, flowers, and fruits from succulents and woody plants, and can be destructive to rangeland when confined and stocked at high densities (Milton *et al.*, 1994). Similarly, the few (<10) onagers at Shaumari may compete with the oryx for forage. Onagers, predominately grazers, browse a large portion of their diet during the dry season in drier habitats (Feh *et al.*, 2002). These other herbivores could have reduced the amount of forage available to the oryx.

There also may have been other causes of declining productivity in oryx, such as genetic inbreeding or outbreeding depression, both of which affected juvenile survival of oryx in Oman (Marshall & Spalton, 2000). The genetics of the Shaumari herd have not been investigated but calf survival trends gave no evidence of such effects. The RSCN attempted to reduce genetic effects by obtaining its founders from two separate stocks but in later years was unable to obtain new genetic stock because of political instability in the region.

Although there were problems inside the reserve the most severe difficulty facing the RSCN was overgrazing outside. Jordan's arid rangelands have been overgrazed and subject to declining levels of rangeland productivity since the 1970s (Hatough *et al.*, 1986). The RSCN and its predecessor, the Royal Jordanian Hunting and Shooting Club, had been seeking to establish new, much larger reserves in the eastern desert since 1965, including one of 950 km² at Burqu (Mountfort, 1965; Clarke, 1979), a permanent water body near the Syria and Iraq borders (Fig. 1). During 1990–1991, however, Bedouins fleeing Kuwait and Iraq during the Gulf War brought 690,000 sheep and 580,000 goats into Jordan, approximately doubling the livestock population (Hashemite Kingdom of Jordan, 1991; Dutton, 1998; CC/EVS/ERM, 2002). After walking up to 1,000 km from Kuwait these animals were starving. They also had higher disease and parasite

loads than local animals (Jones, 1995; Kamhawi *et al.*, 1995; Allonby, 1996; Aldomy *et al.*, 1997; Aldomy & Wilmshire, 1998) and were the probable source of at least one outbreak of *Pasteurellosis* among the oryx during 1990–1991. This livestock influx greatly increased the severity of overgrazing throughout the *badia* but especially around water sources such as Burqu. Burqu was drained dry in 1991 for the first time ever by excessive livestock watering (CC/EVS/ERM, 2002). Therefore, the RSCN was forced to defer the oryx release plans and the new reserve at Burqu was still 'under establishment' in 2000 (Budieri, 2000). These events also precluded the expansion of the Shaumari Nature Reserve from its current 22 km² to the 342 km² that had originally been allocated.

In 2005 the United Nations Compensation Commission recognized the environmental damages from the 1990 Gulf War and awarded Jordan compensation (UNCC, 2005). Some of these funds are to be directed for rejuvenation of the oryx reintroduction programme. With a renewed reintroduction programme, Jordan may begin releasing oryx into the wild within a few years, completing a project started 28 years ago. Notwithstanding its setbacks, Jordan's captive breeding programme produced enough surplus oryx for dispersal to other countries (Table 1), contributing to the increase in the world oryx population and its genetic heterogeneity. In 2003 there were c. 4,000 oryx outside zoos, a 13.5% increase compared to 2001 and a 38.4% increase compared to 2000 (Ostrowski & Anajariyah, 2003).

Acknowledgments

Field investigations by LEH in 2002, 2003 and 2006 and participation in the United Nations Compensation Commission hearings in 2004 were supported by the Hashemite Kingdom of Jordan. Staff at Shaumari, including Aqel Abu-Hammd and Ahmad El Zoubi, assisted our work at the reserve. Information on current policies and conservation plans of the RSCN in 2002 was provided by Yahya Khaled, the Director of Conservation. We thank Adnan Budieri of Envirotech (Amman, Jordan) for information on the reintroduction programme, Majdi

Salameh of the Integrated Management and Information Consultants Company, Amman, for translating portions of the oryx log and other materials from Arabic, and Mohammad Shahbaz of the Badia Research and Development Centre for guiding the Gulf War environmental assessment. We also thank the anonymous referees for their useful reviews.

References

- Abu-Eid, O. (2001) An overview of reintroduction programmes in Jordan. *Al Reem*, **70**, 10–11.
- Abu-Jafar, M.Z. & Hays-Shahin, C. (1988) Re-introduction of the Arabian oryx into Jordan. In *Conservation and Biology of Desert Antelopes* (eds A. Dixon & D. Jones), pp. 35–40. Christopher Helm Ltd, London, UK.
- Aldomy, F.M.M. & Wilsmore, A.J. (1998) Prevalence of toxoplasma antibodies in small ruminants in Jordan. *Pakistan Veterinary Journal*, **18**, 213–215.
- Aldomy, F.M.M., Wilsmore, A.J. & Safi, S.H. (1997) Q fever and abortion in sheep and goats in Jordan. *Sudanian Journal of Veterinary Science and Animal Husbandry*, **36**, 55–61.
- Al-Eisawi, D.M. & Hatough, A.M. (1987) Ecological analysis of the vegetation of Shaumari Reserve in Jordan. *Dirasat*, **14**, 81–94.
- Allonby, E.W. (1996) The effects of disease on the productivity of sheep and goats in Jordan 1986–1996. In *Proceedings, Population and Livestock Related Studies in the Eastern Badia of Jordan*. Jordan Badia Research and Development Programme, Amman, Jordan.
- Bauman, F. (1979) *Environmental Report for Jordan*. Man and the Biosphere Program, US Department of State, Washington, DC, USA.
- Bedin, E. & Ostrowski, S. (2003) Arabian oryx monitoring at 'Uruq Bani Ma'arid Protected Area, Saudi Arabia: population size estimate. *Re-introduction News*, **23**, 30–31.
- Boef, J. (1996) *Oryx Re-introduction Program Phase 2*. Report for the Royal Society for the Conservation of Nature for the Hashemite Kingdom of Jordan, Amman, Jordan.
- Budieri, A. (1995) *Captive Breeding Programme-Biodiversity Country Study*. The Hashemite Kingdom of Jordan report for United Nations Development Programme & Global Environmental Facility, Amman, Jordan.
- Budieri, A. (ed.) (2000) *Jordan Country Study on Biological Diversity: Jordan Ecology Ecosystems and Habitats*. General Corporation for the Environment Protection, United Nations Environment Programme and Global Environment Facility Project No. GF/6105-92-65, GF/6105-92-02(2991), Amman, Jordan.
- Bunaian, F., Hatough, A., Ababaneh, D., Masaqbeh, S., Yousef, M. & Amr, Z. (2001) The carnivores of the northeastern Badia, Jordan. *Turkish Journal of Zoology*, **25**, 19–25.
- CC/EVS/ERM (Consolidated Consultants, EVS Environment Consulting, and Environmental Resources Management) (2002) Monitoring, assessing and quantifying damages to terrestrial ecosystems. In *Population Dynamics Study and Four Studies for Monitoring, Assessing and Quantifying Environmental Damages to Water, Agricultural Resources, Terrestrial and Marine Ecosystems*, pp. 1–37. Report for the Ministry of National Economy, Amman, Jordan.
- CITES (2007) *The CITES Appendices*. <http://www.cites.org/eng/app/index.shtml> [accessed 1 September 2007].
- Clark, B. (1987) The white oryx antelope. *Israel Land and Nature*, **13**, 60–64.
- Clarke, J.E. (1977) Reserve for Arabian oryx. *Oryx*, **14**, 31–35.
- Clarke, J.E. (1979) *A Proposal for Wildlife Reserves in Jordan (IUCN Project 1591)*. Royal Society for the Conservation of Nature (RSCN), Amman, Jordan.
- Conder, P.J. (1981) Water extraction at Azraq. *Ornithological Society of the Middle East Bulletin*, **6**, 8.
- Courchamp, F., Clutton-Brock, T. & Grenfell, B. (1999) Inverse density dependence and the Allee effect. *Trends in Ecology and Evolution*, **14**, 405–410.
- Dutton, R.W. (1998) Population, environment and development. In *Arid Land Resources and their Management: Jordan's Desert Margin* (eds R.W. Dutton, J.I. Clarke & A. Battikhi), pp. 3–20. Kegan Paul International, London, UK.
- EPAA (2003) *Fourth International Conservation Workshop for the Threatened Fauna of Arabia*. Environment and Protected Areas Authority, United Arab Emirates, Sharjah, UAE.
- Feh, C., Shah, N., Rowen, M., Reading, R. & Goyal, S.P. (2002) Status and action plan for the Asiatic wild ass (*Equus hemionus*). In *Zebbras, Asses, and Horses: An Action Plan for the Conservation of Wild Equids* (eds P.D. Moehlman & IUCN/Species Survival Commission Equid Specialist Group), pp. 61–71. IUCN, Gland, Switzerland.
- Hashemite Kingdom of Jordan (1991) *1991 Livestock Census*. Ministry of Agriculture, Amman, Jordan. [in Arabic]
- Hatough, A.M.A. & Al-Eisawi, D.M. (1988) The Arabian oryx in Jordan. *Journal of Arid Environments*, **14**, 291–300.
- Hatough, A.M.A., Al-Eisawi, D.M. & Disi, A.M. (1986) The effect of conservation on the wildlife in Jordan. *Environmental Conservation*, **13**, 331–335.
- Hatough-Bouran, A.M.A. & Al-Eisawi, D.M.H. (1990) Rodent ecology in the Shaumari Wildlife Reserve of Jordan. *Dirasat*, **17B**, 62–85.
- Henderson, D.S. (1974) The Arabian oryx: a desert tragedy. *National Parks and Conservation Magazine*, **48**, 15–21.
- IUCN (2006) *2006 IUCN Red List of Threatened Species*. IUCN, Gland, Switzerland [<http://www.redlist.org>, accessed 17 August 2007].
- Jones, K.C. (1995) Diseases and parasites of livestock of the Badia. In *Population and Livestock Related Studies in the Eastern Badia of Jordan*, pp. 12–17. Royal Scientific Society, Amman, Jordan.
- Jungius, H. (1978) Plan to restore Arabian oryx in Oman. *Oryx*, **14**, 329–336.
- Kamhawi, S., Hijawi, N., Abu-Gazaleh, N. & Abbass, M. (1995) Prevalence of hadatid cysts in livestock from five regions of Jordan. *Annals of Tropical Medicine and Parasitology*, **89**, 621–629.
- Marshall, T.C. & Spalton, J.A. (2000) Simultaneous inbreeding and outbreeding depression in reintroduced Arabian oryx. *Animal Conservation*, **3**, 241–248.
- Milton, S.J., Dean, W.R.J. & Siegfried, W.R. (1994) Food selection by ostrich in southern Africa. *Journal of Wildlife Management*, **58**, 234–248.
- Mountfort, G. (1965) *Portrait of a Desert*. Collins, London, UK.
- Mountfort, G. (1969) Jordan's National Parks. *ARAMCO World*, **20**, 31–37.
- Orshan, G. (1986) Deserts of the Middle East. In *Ecosystems of the World Vol. 12* (eds M. Evenari, I. Noy-Meir & D.W. Goodall), pp. 1–28. Elsevier, Amsterdam, The Netherlands.
- Ostrowski, S. & Anajariyah, S. (2003) *2002 Middle East Arabian Oryx Disease Survey*. National Wildlife Research Center, Taif, Saudi Arabia.

- Ostrowski, S., Bedin, E., Lenain, D.M. & Abuzinada, A.H. (1998) Ten years of Arabian oryx conservation breeding in Saudi Arabia - achievements and regional perspectives. *Oryx*, **32**, 209–222.
- Price, M.R.S. (1986) The reintroduction of the Arabian oryx (*Oryx leucoryx*) into Oman. *International Zoo Yearbook*, **24/25**, 179–188.
- Quemsiyeh, M.B., Amr, Z. & Budieri, A. (1996) Status and conservation of Artiodactyla (Mammalia) in Jordan. *Mammalia*, **60**, 417–430.
- Saltz, D. (1998) A long-term systematic approach to planning reintroductions: the Persian fallow deer and the Arabian oryx in Israel. *Animal Conservation*, **1**, 245–252.
- Seddon, P.J., Ismail, K., Shobrak, M., Ostrowski, S. & Magin, C. (2003) A comparison of derived population estimate, mark-recapture, and distance sampling methods to estimate the size of a desert ungulate, the Arabian oryx. *Oryx*, **37**, 286–294.
- Spalton, J.A. (1993) A brief history of the reintroduction of the Arabian oryx (*Oryx leucoryx*) into Oman 1980–1992. *International Zoo Yearbook*, **32**, 81–90.
- Spalton, J.A., Lawrence, M.W. & Brend, S.A. (1999) Arabian oryx reintroduction in Oman: successes and setbacks. *Oryx*, **33**, 168–175.
- Treydte, A.C., Williams, J.B., Bedin, E., Ostrowski, S., Seddon, P.J., Marschall, E.A., Waite, T. & Ismail, K. (2001) In search of the optimal management strategy for Arabian oryx. *Animal Conservation*, **4**, 239–249.
- UNCC (2005) *Report and Recommendations Made by the Panel of Commissioners Concerning the Fifth Installment of "F4" Claims.*

- United Nations Compensation Commission Security Council S/AC.26/2005/10, Geneva, Switzerland.
- Verhulst, P.F. (1838) Recherches mathématiques sur la loi d'accroissement de la population. *Memoirs de l'Academie Royal Bruxelles*, **18**, 1–38.

Biographical sketches

Lee Harding is a wildlife biologist whose research interests include ungulates, large carnivores and fur bearers in tundra, temperate and arid ecosystems. Formerly with the Canadian Wildlife Service, he now owns and manages SciWrite Environmental Sciences Ltd. He led the team that assessed the damage to terrestrial and wetland ecosystems in Jordan caused by the 1990–1991 Gulf War. Omar Abu-Eid has been involved in the captive breeding programmes of the Royal Society for the Conservation of Nature (RSCN) in Amman since 1999. He is currently the Programme Assistant and the Environment Focal Point at the European Union delegation to the Hashemite Kingdom of Jordan. Nashat Hamidan has been an ecologist with RSCN since 2000 and is responsible for providing technical advice on management of the Arabian oryx herd at Shaumari. His research interests include fish, birds and reptiles in desert oasis ecosystems. Ahmad al Sha'lan began working at the Shaumari Nature Reserve in 1984 and has been the Reserve manager since 1998. His interests are in oryx and their management in captivity.