1. General introduction

Asiatic houbara bustards (henceforth houbara, *Chlamydotis [undulata] macqueenii*) are widely distributed across Central and Eastern Asia, and the Middle East (Dement'ev & Gladkov 1951, Heim de Balzac & Mayaud 1962, Ali & Ripley 1980, Cramp & Simmons 1980, Johnsgard 1991, del Hoyo *et al.,* 1996). They are large (weighing 1.1 – 2.2 kg, Cramp & Simmons 1980), and are frequently hunted for food and sport (Saint Jalme *et al.,* 1996a). Despite their wide distribution, and status as an important prey species for falconers (Seddon *et al.,* 1995), they remain a poorly studied species, and data on breeding, movements, displays, distribution and feeding ecology are rarely quantified and reported. Two factors have limited the scientific study of this species. First, they live in some of the most remote and inhospitable places on earth, and second, the species is extremely cryptic, and individuals are difficult to catch, mark and observe (e.g., Combreau & Launay 1996, Launay *et al.,* 1997, Seddon *at al.,* 1999).

Developing a better understanding of the breeding behaviour, movements, and ecology is important for this species; in particular, it will aid houbara conservation through identification and protection of suitable areas of habitat throughout its range (Seddon *et al.,* 1995, Saint Jalme *et al.,* 1996a, Saint Jalme *et al.,* 1996b). In addition, better breeding data will provide a quantitative basis for developing models to help predict changes in population size, and identify life history phases that are most sensitive to threats. At a proximate level, monitoring survival, breeding performance, behaviour and movements are important steps in the reintroduction of any species, and provide the basis by which the success or failure of the release programme can be adequately and accurately assessed (IUCN 1998, Seddon 1999).

Three events have made research on houbara easier in the 1990s than has previously been possible. First, there is an increasing awareness that houbara numbers are declining in much of their range, particularly among the Arab states in the south eastern range area (Jennings 1988, Seddon *et al.,* 1995), and this has aided the funding of conservation projects directed at preserving houbara habitat. Second, there has been a number of captive-breeding centres established that are attempting to breed houbara for later release, principally into protected reserves, but ultimately with the aim of re-establishing the species over much of its former range (Saint Jalme *et al.,* 1996b). Third, the use of solar-powered and satellite radio-transmitters has enabled researchers to track houbara remotely at a local and regional level (e.g., Osbourne *et al.,* 1997, Combreau & Smith 1998), and many released individuals can be tracked. However, despite these advances, few long-term studies of houbara in the wild have been completed.

In Saudi Arabia, as over much of the species' range, houbara are in apparent decline in distribution and in abundance (Seddon *et al.,* 1995). There have been two principal responses by the Saudi Arabian government to these declines: the establishment of a series of protected reserves throughout the country, where the primary threats of hunting and grazing are controlled or prevented, and the development of a captive-breeding centre where houbara are bred for release into the wild (Seddon *et al.,* 1995, Saint Jalme *et al.,* 1996b). The aim of the captive-breeding programme in Saudi Arabia is to establish self-sustaining populations of houbara in areas from which they have been extirpated, and to prevent local extinction of breeding populations (Seddon *et al.,* 1995).

Initial foci of captive breeding have been on development of breeding and rearing techniques, and establishment of a self-sustaining captive flock. By 1991, young houbara were first available for release, and releases into Mahazat as-Sayd Reserve, in west central Saudi Arabia, have continued since that time (Saint Jalme *et al.,* 1996b, Combreau & Smith 1998). A successful release project has three main phases. First, release methods need to be developed and tested. Second, post-release monitoring of the success of the project should be undertaken (and can include a range of measures of success), and third, when sufficient releases have been undertaken to establish the population, monitoring should determine whether the population is self-maintaining. Ultimately, the only success measure needed is to show that recruitment equals or exceeds mortality and emigration (i.e., the population is self-sustaining). However, several interim measures (e.g, survival and establishment of released birds at the release site, production of eggs, chicks and fledglings, and juvenile survival) are all important components of a release programme, because they provide checks on success and limitations as the project develops.

Focus of this study

In July 1995, at the start of my study, houbara had been released into Mahazat as-Sayd Reserve over the previous three years with moderate success (Combreau & Smith 1998).

The initial focus of their research was on development of release methods, with some post-release monitoring of young birds to examine the cause of mortality, and movements (Combreau & Smith 1997, 1998, Combreau *et al.*, 2000). One nest was found in May 1995, and this was the first evidence of breeding by this released population (Gélinaud *et al.*, 1997). My approach in this study was: first, to test release methods further, with the aim of improving survival rates of released birds and identifying parameters that influenced release success, and second, to study closely the released population to determine breeding success, nesting habitat, male display behaviour, home range and movements.

In this thesis, I report on three years of releases of houbara into Mahazat as-Sayd Reserve, and the subsequent survival, movements, breeding ecology and behaviour of the released birds. Specifically, in Chapter 3, I test the effectiveness of predator control at release sites using a standard release method, and determine important causal factors influencing predation rates of newly released houbara. In Chapter 4, I detail breeding parameters: clutch and egg size, incubation and fledging periods, breeding success and causes of breeding failure, and I relate timing of nesting to rainfall and female experience. In Chapter 5, I describe habitat characteristics of female nest sites and test whether these sites are randomly located compared to available habitat within the reserve. In Chapter 6, I measure home range areas, distance between locations, and seasonal site fidelity of adult houbara within the reserve. I use interaction analyses and range centre spacings to examine the role of social behaviours and breeding status in determining home range size and houbara distribution. In Chapter 7, I present results of the first detailed study of male breeding display behaviour in the wild, and test whether males differ in their display intensity within seasons. In Chapter 8, I apply lek theory to the data reported in Chapters 4, 6, and 7, to test the hypothesis that male leks are located at hotspots of female activity. Finally, in Chapter 9, I discuss the significance of these results in the context of the value of reintroductions as a tool for establishing populations, and in understanding houbara ecology and behaviour, and I provide recommendations for future research and management of houbara.

2. General methods

Study area

The 2240 km^2 Mahazat as-Sayd Reserve (22°10' N, 41°45' E), west-central Saudi Arabia (Fig. 2.1), was created in 1989 in an area of semi-arid desert steppe habitat on the Nadj pediplain as a release site for houbara, Arabian Oryx (*Oryx leucoryx*), Sand Gazelle (*Gazella subgutturossa*) and Ostrich (*Struthio camelus*; Greth & Smith 1993, Smith & Haque 1994, Haque & Smith 1996, Combreau & Smith 1998). The perimeter of the reserve was fenced in 1990 to exclude domestic grazing stock, and since that time cover of vegetation, and floral species composition have increased dramatically (S. Collenette pers. comm.). The reserve is at 1000 m a.s.l., and is generally flat. Vegetation cover is greatest in temporary water lines and depressions, which channel and collect water during patchy infrequent rain. Uneven run-off and localised showers create a mosaic of green and dry vegetation patches. There is no permanent water in the reserve. Mean rainfall is 79 mm per year. Summers are hot (mean = 32.6 – 33.0 °C, absolute maximum 46.0 °C; Seddon 1997), and winters are mild (mean = 17 – 18 °C, see Appendix 1). Temperature and rainfall data were collected from one meteorological weather station situated at the Bird Camp, and additional rainfall data were collected manually from 16 other gauges spread throughout the reserve (Fig. 2.2).

The region in which the reserve is situated was a regular hunting ground for wintering houbara. The location, extent, and size of the wintering population are unknown. Incidental observations and oral tradition record houbara formerly breeding in the area (Seddon 1997), but because the surrounding area is heavily over-grazed and frequently hunted, it is unlikely that natural populations of houbara now regularly breed in the region.

Study animal

Houbara are cursorial cryptic desert birds weighing 1.1 – 2.2 kg belonging to the African based Otididae. They are sexually dimorphic: males are about 20 % larger than females (Cramp & Simmons 1980). Little is known about houbara ecology in the wild. They are omnivorous opportunistic generalists, feeding on a wide range of invertebrates, fruits, and vegetative plant material (Combreau & Smith 1997, Tigar & Osbourne 2000, and references therein).

Traditionally, three subspecies of houbara bustards have been recognised. These are the nominate race, *Chlamydotis undulata undulata* [Jacquin 1784], North Africa; *C. u. fuertaventurae* [Rothschild & Hartert 1894], Canary Islands; and *C. u. macqueenii* [Gray 1832], Asia and the Middle East (Cramp & Simmons 1980, del Hoyo *et al.,* 1996). The races differ markedly in their appearance and behaviour and there is little overlap or mixing between them (Gaucher *et al.,* 1996, and see below). Asiatic houbara on the Arabian Peninsula are either resident breeders, or they migrate to central Asia (Seddon & van Heezik 1996, Osbourne *et al.,* 1997). In Saudi Arabia, a remnant population breeds in the north of the country, and conservation emphasis is on protection of habitat through reserve creation for wild houbara, and the reintroduction of houbara into reserves to replace extirpated populations (Seddon *et al.,* 1995, Saint Jalme *et al.,* 1996b, Seddon & van Heezik 1996).

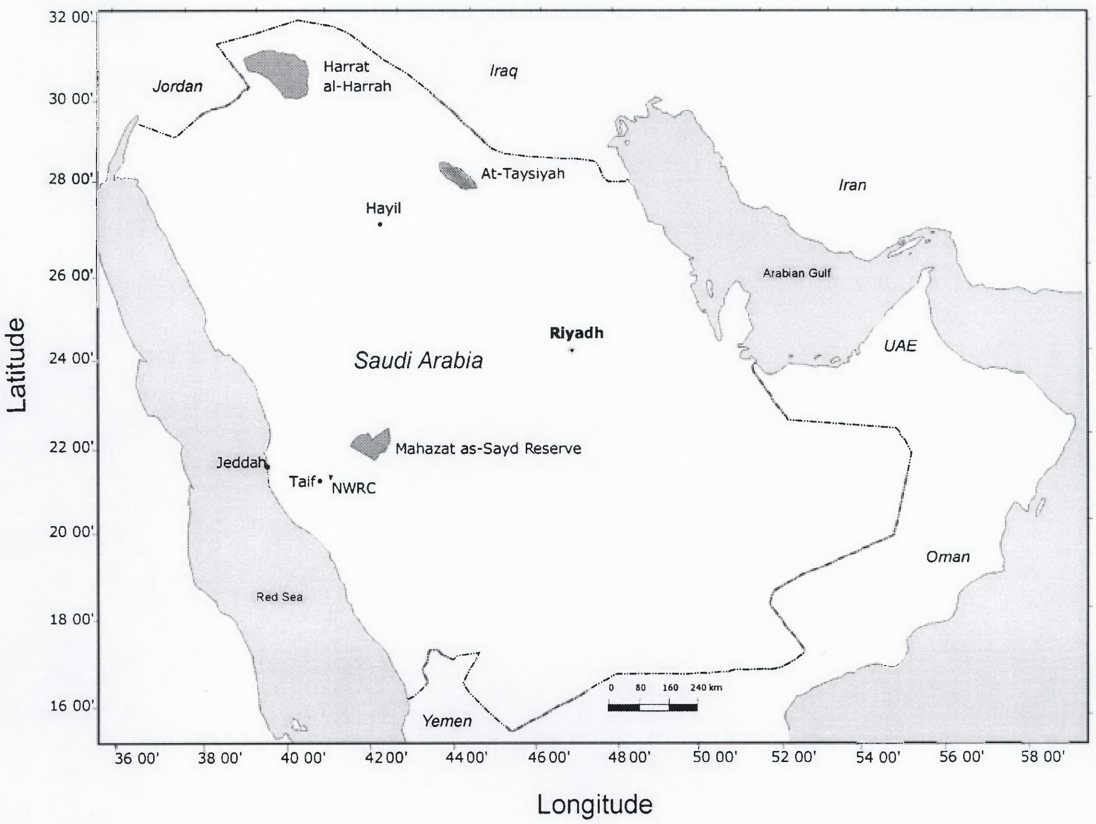

Figure 2.1: Map of the Arabian Peninsula, showing the location of Mahazat as-Sayd Reserve in Saudi Arabia, and other reserves mentioned in the text. All houbara released in Mahazat as-Sayd Reserve were raised at the NWRC (National Wildlife Research Centre).

Houbara bred from captive stock at the National Wildlife Research Centre (NWRC) in Taif, 220 km south west of the reserve, have been reintroduced into Mahazat as-Sayd Reserve from 1991 onward (Seddon & Maloney 1996, Combreau & Smith 1998). In this study, I intensively monitored the entire resident population. Tracking houbara was possible because all released houbara were fitted with 60 g back-mounted solar-powered radio-transmitters (Telemetry Systems Inc., Mesquon, WI, USA; or AVM Instrument Co. Ltd., Livermore, CA, USA) at the time of release, and many units were working well over five years after birds were released. A small (25 x 50 mm) linoleum pad was glued to the base of the transmitter, before the transmitter was attached to the bird. Harnesses were elastic cord threaded into a teflon material tube, looped over the base of the wings and tied (cotton thread and superglue) across the upper breast. Harnesses did not noticeably restrict walking or flying movements. The attachment system is similar to that used on satellite tags attached to houbara that migrate from Central Asia to the Middle East (Combreau *et al.*, 1999). I considered that the radio-tagged population was close to the total population, because very few houbara fitted with transmitters that disappeared were ever seen again, and few non-tagged adults were ever located. With few exceptions, the occasional random encounters with houbara when I was driving, watching male displays, and following tracks on foot, were of identifiable houbara with active transmitters.

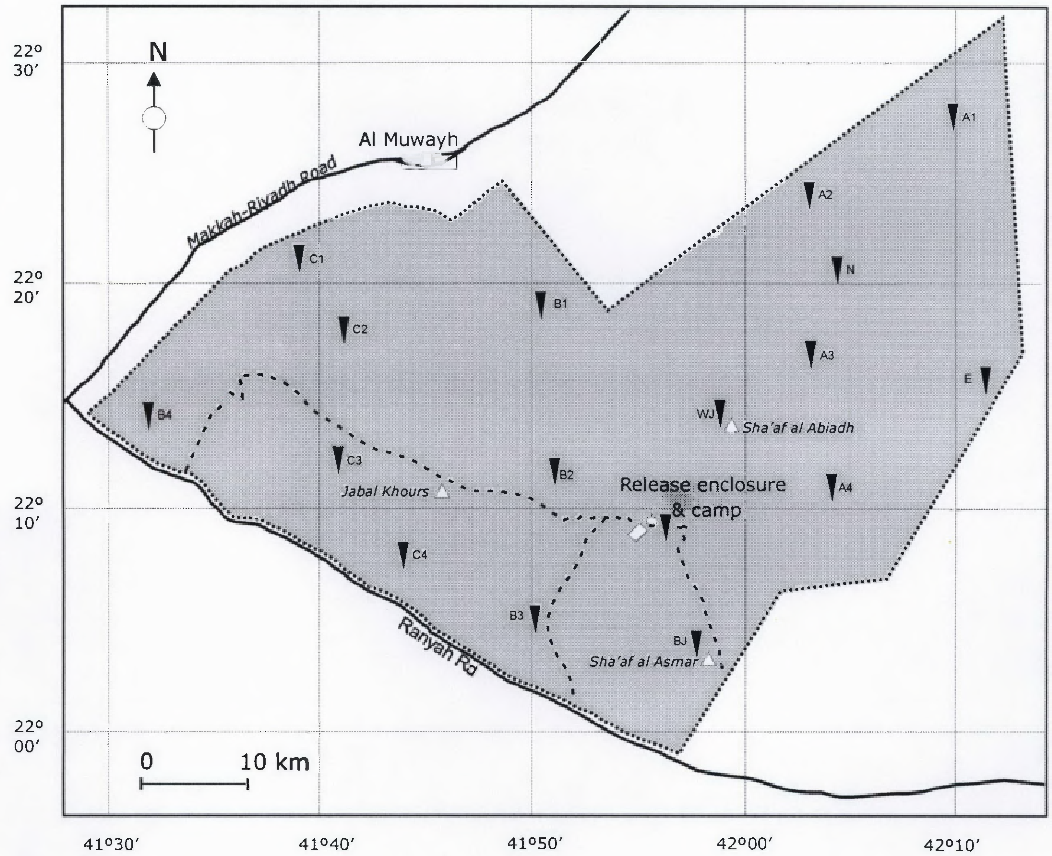

Figure 2.2: Map of Mahazat as-Sayd Reserve (shaded area) showing the location of major tracks (dotted lines), small hills (open triangles), rain gauges (inverted closed triangles), camp and release enclosure. Rain gauge codes are given in full in Appendix 1. The meteorological station was located at the camp. Axes details as for Fig. 2.1.

Regular extensive aerial searches of the reserve and surrounding area that covered 28 000 km^2 (140 x 200 km) located few houbara with active transmitters, and I consider that most missing birds were either dead, or had dispersed very widely. No breeding activity was recorded for houbara without transmitters.

Year round, houbara were located two to three times per week from the air, using a single-engine Maule aircraft flying at 300 m a.g.l., fitted with two side-mounted two-element yagi directional aerials, and using a scanning receiver (Teleonics Inc. Mesa, AZ., USA), and a minimum of once per week on the ground, using a 5-m-high four-element yagi aerial mounted on a four-wheel-drive vehicle. Approaches during ground tracking were to a distance at which visual contact was made, or until a moving signal from the bird was pinpointed to an area of less than 1 ha. Latitude and longitude co-ordinates were recorded for all locations by GPS. Errors associated with tracking houbara from the ground and in the air are reported in Appendix 2.

Nomenclature of houbara

Recently, a split of houbara bustards into two species based on species-level differences in behaviours, calls, distribution, morphology, and in mitochondrial DNA has been recommended (Gaucher *et al.,* 1996, Sangster 1996). In the split proposed by Gaucher *et al.,* (1996), the Asian or Middle Eastern sub-species *C. u. macqueenii,* would become *C. macqueenii,* a sibling species to *C. u. undulata* and *C. u. fuertaventurae*. Problematic in this split is the use of the same common name, "houbara bustard", for the North African *C. u. undulata* and the Asian *C. u. macqueenii.* Gaucher *et al.,* (1996) did not discuss the use of common names when they suggested this split, and the precedence for use, and standardisation of common names remains unresolved among houbara bustard practitioners. Suggested or current names for each of the newly separated species include Asiatic Houbara Bustard (Seddon *et al.,* 1999), Macqueen's Bustard, Eastern Houbara, Macqueen's Houbara Bustard for *C .u. macqueenii* and Western Houbara, Western Houbara Bustard for *C. u. undulata*, and *C. u. fuertaventurae* (B. Dawson *in litt.*). Other authors used houbara bustard, or houbara as a common name, but have chosen to continue with the use of the sub-specific trinomial (*C. u. macqueenii*) for *C. macqueenii* (e.g., Seddon & van Heezik 1996, Combreau *et al.,* 1999), or have used a *C. [u]. macqueenii* notation (e.g., van Heezik & Seddon 1999, Combreau *et al.,* 2000, Maloney 2001, Yang *et al.,* 2002). In this thesis I use the *Chlamydotis [undulata] macqueenii* nomenclature used in most recently published papers, by most authors who work throughout the range of *C. [u.]. macqueenii.* As a common name, I adopt the recent practice of referring to *C. [u.] macqueenii* as Asiatic houbara, or Asiatic houbara bustard (e.g., van Heezik *et al.,* 2002, Yang *et al.*, 2002). I use the term "houbara" throughout the thesis to refer to the Asiatic houbara bustard (*C. [u.] macqueenii*). To avoid ambiguity, in relation to discussion on the North African, *C. u. undulata,* or the Canarian, *C. u. fuertaventurae*, I use Latin names at every referral to *undulata* and *fuertaventurae*.

3. Factors affecting survival of captive-reared sub-adult Asiatic houbara (*Chlamydotis [undulata] macqueenii*) released into Mahazat as-Sayd Reserve, Saudi Arabia.

Abstract

I reintroduced 152 sub-adult Asiatic houbara (*Chlamydotis [undulata] macqueenii*) into Mahazat as-Sayd Reserve, a 2250 km^2 protected area in west central Saudi Arabia, as part of an ongoing programme to re-establish the species into formerly occupied habitats. Released houbara were captive-bred and hand-raised to a minimum of 53 days old before being transported, held for 4 – 37 days, then released. No birds died in transport, 6 % died before release, mostly from trauma in holding cages. Releases took place in a mammal-free enclosure in 1995 to 1997, or from holding cages directly into the reserve in 1997. Predator control occurred adjacent to all release sites. Releases were considered successful; 27 % of birds were recruited into the breeding pool, 20 % survived for more than 1 – 3 years. Mortality rates were very high immediately after release, 14 % of all released houbara died in the enclosure, 52 % died in the reserve. Mean time from release to death was 38.9 days, and 50 % of all released birds were dead within 14 days of release. Mean distance from the release to death site was 3.5 km (50 % died within 0.9 km) for enclosure releases and 3.9 km (50 % died within 1.6 km) for reserve releases. In total, 76 of 79 deaths in the reserve were due to predators, and of 26 cases where cause of death was known: 81 % were by foxes (*Vulpes spp.*), 8 % by avian predators, 8 % by cats (*Felis spp.*), and one houbara was hunted by humans. Mortality was significantly higher during moonlit nights, and for releases directly into the reserve compared to into the enclosure. Release year, age and sex of released birds, release group size, temperature after release and rainfall prior to release were not significantly related to probability of survival. Predators regularly killed houbara within a predator-trapping zone, and predator control did not increase distance or time from release to death. Rates of predation-related mortality increased over time because released birds declined into poor health, translocated red foxes and feral cats returned to the release site, and other predators may have been implicated. I emphasise the need for long-term monitoring of release projects. I suggest that radically different approaches to the current release format are warranted, such as total predator eradication at release sites, the development of mobile release techniques, and releases in winter when climatic conditions are more favourable, if better survival rates of houbara following releases are to be made.

Introduction

Reintroduction programmes

Reintroductions are attempts to re-establish a species within an area in which the species was formerly present (IUCN 1998). They are invariably expensive and long-term procedures, and to be successful they require a co-ordinated team approach before, during, and after the release phase (Beck *et al.,* 1994, IUCN 1998, Seddon 1999, Fischer & Lindenmeyer 2000). Stock for reintroductions can come from other wild populations in direct wild-to-wild translocation, or from captive breeding programmes. A frequent motivation for establishing captive breeding programmes is for species conservation (e.g., Nesbitt & Carpenter 1993, Powell *et al.,* 1997, Biggins *et al.,* 1999, Maloney & Murray 2002), particularly when populations in the wild are rare or threatened. The underlying tenet of such reintroduction programmes is that new populations of the species can be established.

This tenet is not always adequately tested. Ideally, success of a release programme would be judged on the lifetime reproductive fitness of released individuals or the establishment of a self-sustaining population (e.g., Griffith *et al.,* 1989, Sarrazin & Barbault 1996, Fischer & Lindenmayer 2000). Clearly, these are difficult criteria to measure, and can require many years of releases and significant resources. More immediate measures, such as recruitment into the breeding pool and initial breeding success, can be used to indicate that an individual has successfully established in the wild. Again, few studies follow released individuals at an intensity that allows this measure to be well quantified. Most studies that measure success do so by recording survival post-release for a pre-determined length of time, usually a few months beyond the release period (e.g., Combreau & Smith 1998), or until a pre-determined behaviour is recorded (e.g., Lohoefener & Lohmeier 1986). Whatever the case, all of the above measures of success can only ever be judged at a point in time, and this can result in some projects that were initially declared successful later being reclassified as unsuccessful (e.g., Hambler 1994, Wolf *et al.,* 1996). A better approach may be to set three objectives: survival, breeding of released individuals, and persistence of the population, then undertake continued monitoring that allows each population parameter to be adequately defined and reported at any time (Seddon 1999, Fischer & Lindemayer 2000).

Few programmes that release animals are successful by any of the above criteria (Griffith *et al.*, 1989, Beck *et al.*, 1994, Fischer & Lindemayer 2000). Those that are successful have several features in common: they release more birds over a longer time period, do more pre-release screening (e.g., monitoring for diseases) and more post-release feeding, and provide more local employment and community education programmes than do unsuccessful projects (Griffith *et al.*, 1989, Beck *et al.*, 1994). Commonly, failures in programmes are because releases take place in the continued presence of threatening processes such as anthropogenic habitat degradation (e.g., Viggers *et al.*, 1993), exotic predators (e.g., Short *et al.*, 1992), or hunting for sport or food. Therefore, reintroduction programmes have a better chance of success if they are undertaken within protected or managed sites where these processes have been reduced or eliminated.

Houbara reintroduction in Saudi Arabia

In Saudi Arabia, Asiatic houbara (*Chlamydotis [undulata] macqueenii*) have been extirpated from most of their former range through a combination of habitat degradation from over-grazing and extreme hunting pressure on adults (Jennings 1988, Seddon *et al.*, 1995, Saint Jalme *et al.*, 1996b, Seddon & van Heezik 1996). The National Commission for Wildlife Conservation and Development was established in 1986 to oversee wildlife conservation in Saudi Arabia (Saint Jalme *et al.*, 1996b). The Commission has established a series of large protected areas, up to about 13 000 km^2 in area, in which grazing and hunting has been limited or excluded. In addition, captive breeding centres for a number of native animals (principally houbara, oryx (*Oryx leucoryx*) and sand gazelle (*Gazella subgutturossa*)) have been built for the purpose of providing founder stock for wildlife restoration projects in these protected areas. For houbara, the Commission's aim was to establish a self-sustaining captive population that would provide surplus stock for release into protected areas and thereby bring about the restoration of resident houbara populations in Saudi Arabia (Saint Jalme *et al.*, 1996b). By 1991, the first part of this goal was achieved, when first releases of surplus houbara occurred into one such protected area, Mahazat as-Sayd Reserve (Combreau & Smith 1998). However, because predators killed all of those first few released birds, an experimental approach for determining suitable release methods was instigated (Seddon *et al.*, 1995, Combreau & Smith 1998).

Combreau & Smith (1998) tried three different release techniques over three years from 1992 to 1994, releasing a total of 85 birds into a 400 ha fenced enclosure that was free from mammalian predators. They compared releases of houbara broods, wing-clipped sub-adults and flying sub-adults. Because in 1993 many released sub-adults were killed by predators when they flew from the enclosure and entered the reserve, in 1994 they trapped red foxes (*Vulpes vulpes*) in a 36 km^2 area centred on the release site, and translocated them 15 to > 60 km from the enclosure. Released flying sub-adult houbara survived better (48 %) than chicks or wing-clipped adults, and for all three groups combined 36 % of released birds were "successfully" introduced into the reserve. First breeding from these birds was recorded in 1995 (Gélinaud *et al.,* 1997). Combreau & Smith (1998) concluded that (1) predators killed most houbara after release, (2) the survival of houbara was positively related to time spent in the 400 ha enclosure after release, but not to age, and (3) predator control affected where and when houbara would be killed but not the overall rate of predation. They recognised that group sample sizes were small and there was little replication (temporal or spatial) of these results. They suggested that other techniques, such as releases of birds directly into the reserve without a holding period, may be worth further consideration.

My approach

In 1995, I began research on the release and survival of houbara in Mahazat as-Sayd Reserve. I initially chose to continue with the flying sub-adult protocols, maintaining the predator control set in place by Combreau & Smith (1998). I did this because Combreau & Smith had based their conclusions – that flying sub-adult releases achieved a 48 % success rate – on data taken from two years that differed in predator control at the release site (no translocation of predators in 1993, translocation over varying distances in 1994). Further, Combreau & Smith (1998) reported that one quarter of foxes that they translocated were recaptured back at the release site, but they did not discuss potential implications of this finding to post-release survival of sub-adult houbara. Two features of this predator translocation method may affect the future success of the release project. First, because foxes may become more wary of capture following handling and translocation, trapping may not continue to capture all predators living near the release site – that is, there may be a "cryptic predator" effect. Second, repeated releases of houbara at the same site and time of year may provide predators with a guaranteed regular food source – that is, there may be a "predator learning" effect. I predicted that such a predator translocation method would eventually lead to a reduction in survival rates of released houbara compared to the first years of release. I tested this prediction by maintaining a similar release protocol for three further years, while concurrently measuring survival rates of sub-adults. I continued to cage trap predators in 1995, then intensified this cage trapping, and added a leg-hold trapping method in 1996 to determine whether "cryptic" cage shy predators were present. Leg-hold traps (Victors soft-jaw traps Model 3.0) were buried in sand and should be difficult for approaching predators to detect, so should have higher catch probabilities. In 1997, I also tested an alternative release method, at mobile sites away from the release enclosure.

In addition, post-release survival of houbara may be related to a number of intrinsic and extrinsic factors. Age and sex of released birds are two commonly considered variables. Male houbara are up to 20 % larger than females (del Hoyo *et al.,* 1996), and if there are gender-related differences in habitat use and ability to defend themselves against predators then differential predation rates may occur. Post-release survival may also be linked to rainfall and temperature. In the absence of rain and in hot dry conditions, feeding activity by both houbara and their predators may become concentrated on patchy foraging sites (Combreau & Smith 1998). At these sites, the probability of houbara-fox encounters may increase, leading to increased predation rates.

In this chapter, I report on the survival and recruitment of sub-adult houbara released into Mahazat as-Sayd Reserve from 1995 to 1997. Specifically, I:

(1) measure the post-release survival and rate of recruitment of sub-adult houbara;

(2) identify causes, timing and location of mortality;

(3) test the predictions that predation rates would continue to increase as predators learned to avoid capture (cryptic predator effect) or targeted released houbara (predator learning effect);

(4) test the prediction that using different release sites for each release would result in increased survival of sub-adult houbara in Mahazat as-Sayd Reserve, and;

(5) test whether intrinsic (age at release, sex of released birds) or extrinsic (ambient temperature, rainfall, moonlight during and after release) factors affected post-release survival.

Methods

Transport and releases of sub-adult houbara

Sub-adult houbara were hatched and reared from captive stock at the National Wildlife Research Centre (NWRC), in Taif, 220 km south west of Mahazat as-Sayd Reserve. Captive stock was sourced from Pakistan in 1987 and 1988 (van Heezik *et al.,* 2002). At NWRC, the captive breeding season extended from January to May, and therefore young were produced in small numbers throughout that period. Fertile eggs were collected one at a time following artificial insemination, and the resulting chicks were housed and raised in groups of four or five. These birds were not usually related to each other, but were of a similar and known age. Once the youngest chick of the group reached about 60 days and at the convenience of staff at the captive centre, chicks were treated for Newcastle disease, avian pox and parasites, and given a full health check including choanal and cloacal swabs, and blood, serum, bacteria and virus screens (Ostrowski 1995). Healthy birds were then weighed and placed in transport cages ready for release in the reserve. Transport to Mahazat as-Sayd Reserve was by vehicle (2 hrs) or by light aircraft (45 mins). Once at the reserve, a solar-powered backpack harness transmitter (Telemetry Systems Inc., Mesquon, WI, USA; or AVM Instrument Co. Ltd., Livermore, CA, USA) was fitted and an individually numbered metal ring placed on the tarsus. In 1997, a single year code colour ring was added to the other tarsus to aid field identification. All birds were sexed on arrival at the reserve using a combination of weight, bill, tarsus, and foot measurements. Foot length and width was a particularly reliable method of sexing birds older than 60 days, with males being larger than females (Maloney 2001, Appendix 3). Genetic sexing techniques were not available for this study.

Protocols for release varied between years (Table 3.1). All releases in 1995 and 1996 and Groups 4 – 6 in 1997 followed the flying sub-adult protocol of Combreau & Smith (1998). Sub-adults were held in nylon mesh-covered 2.8 m diameter x 0.8 m high “soft-cages” (see Combreau & Smith 1998) located inside a mammalian predator-free enclosure for approximately one week to recover from transportation and transmitter attachment. Releases of Group 1 – 3 birds in 1997 took place in three different sites, 10, 14, and 20 km from the enclosure. At these release sites a 40 m long x 2 m wide x 1.5 m high soft cage was constructed (Fig. 3.1). The cage was surrounded by two 1 m high Gallagher electrified sheep netting fences, and mammalian predators were cage-trapped in a grid surrounding the release site (Table 3.2). The mammalian predator-free enclosure was 400 ha in size, surrounded by a 2 m high, 2 x 2 km long chain mesh electrified fence built in 1989 (Fig. 3.2). Foxes and cats were removed from inside the fence by 1990, and no mammalian predators have been detected inside the enclosure since that time. After 4 – 37 days inside the soft cages in the enclosure, sub-adult houbara were released by opening the cage and letting the birds leave of their own free will, usually within one hour of opening the cage door. Birds were then free to forage inside the enclosure on natural food, or to leave the enclosure by flying over the fence. A list of all houbara released from 1995 to 1997 is given in Appendix 4.

Figure 3.1: (A) Example of interior of "soft" cages used to hold houbara at the three release sites in Mahazat as-Sayd Reserve in 1997.

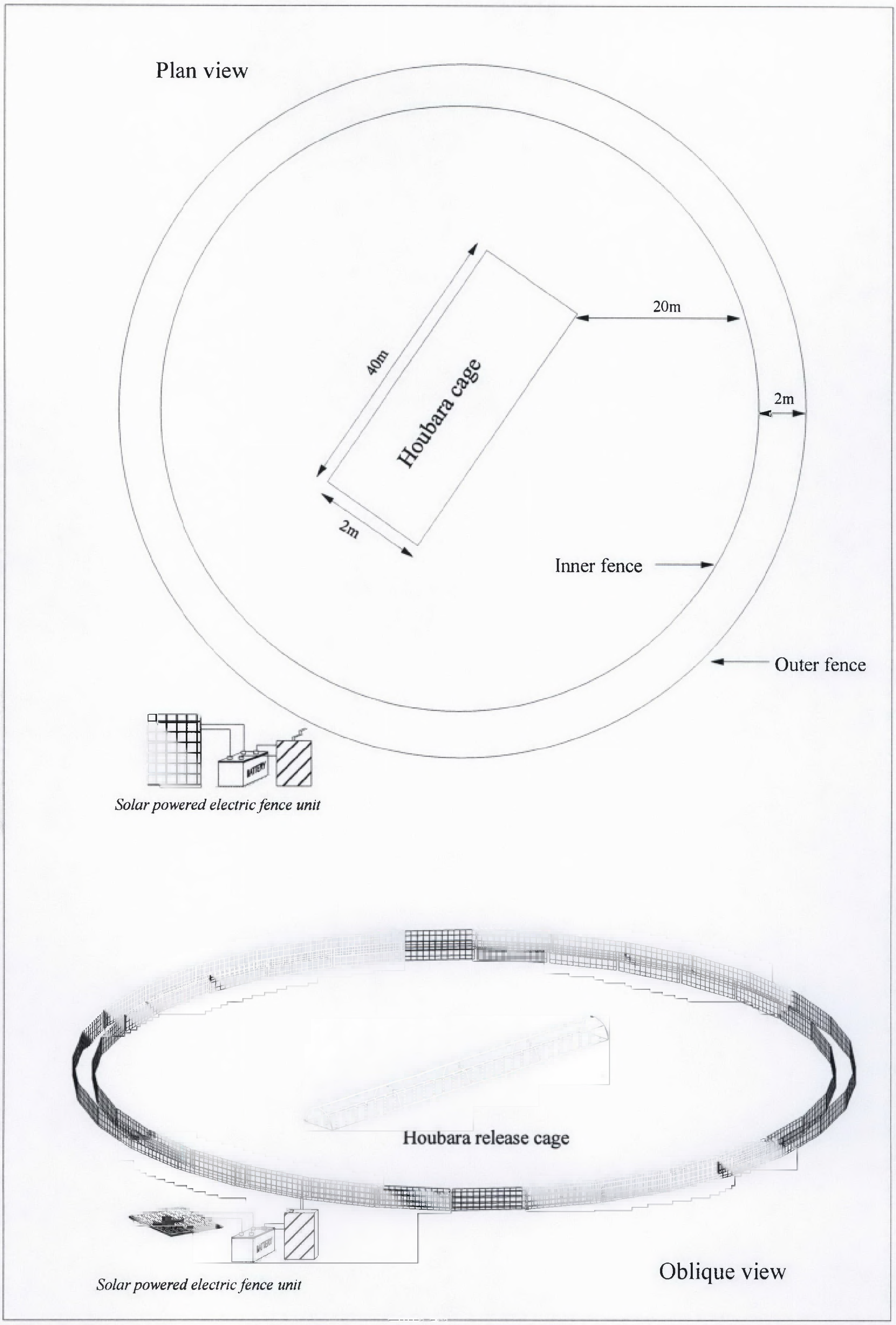

Figure 3.1: (B) Plan and oblique views of the "soft" cage design used to hold houbara at the three release sites in Mahazat as-Sayd Reserve in 1997.

Figure 3.2: A section of the 4 km^2 mammalian predator-proof enclosure for houbara, showing fence design and general habitat. Soft cages were set back more than 200 m from the fence-line. No mammalian predators breached the fence during the three-year study.

Other protocols used on released birds

Other researchers undertook experimentation on released houbara in Mahazat as-Sayd Reserve (Table 3.1). Two studies; on predator awareness training in 1996 and 1997 (van Heezik *et al.*, 1999), and on feeding and energetics in 1997 (Lacroix 1998) ran concurrently to my study, and may have compromised my ability to detect differences in survival. However, experimental and control groups for these two studies were evenly spread amongst all groups. While their treatments may have also influenced survival rates, I assumed that any influences of the variables I examine here would be detectable if they were operating at a biologically significant level for released houbara. As such, their experiments are not reported here.

Table 3.1: Release and conditioning protocols for houbara sub-adults released into Mahazat as-Sayd Reserve from 1995 to 1997. Each group consists of similar aged, mixed gender sub-adults that were housed, transported, and released together.

Protocols	1995	1996	1997
A: Held in 2.8 m cages (0.8 m high) for one week, released into 400 ha enclosure, left enclosure whenever they chose	All groups	All groups	Group 4 – 6
B: Held in 2 m x 30 m (1.5 m high) cages for one week, released directly into reserve	-	-	Groups1 – 3
C: Predator conditioning (van Heezik *et al.,* 1999)	-	Half of all groups	Half of all groups
D: Food conditioning (Lacroix 1998)	-	-	Half of each group
Number of groups released	10	6	6
Total number of birds released	44	42	66

Capture of predators

Traps were set at the release enclosure in all three years, and at the three reserve release sites used in 1997. At the enclosure site a grid of 23 cage traps was set in a zone extending 2 km around the outer perimeter of the enclosure to reduce densities of mammalian predators in the area adjacent to the enclosure (Fig. 3.3). Traps were set for three nights every fortnight in 1995 and for seven nights per fortnight in 1996 and 1997. Dates of opening and numbers of trap nights are given in Table 3.2. Traps were checked daily and rebaited with fresh chicken pieces as required. On 13 nights in May 1996, 24 Victor 3.0 leg-hold traps were set under bushes and hazed with sand at sites midway between cage traps. At the reserve sites in 1997, 30 cage traps were set in a 2.5 x 3 km grid at Release Site 1, and 25 cages were set in a 2.5 x 2.5 km grid at each of Sites 2 and 3. Release or translocation protocols for all cage and leg-hold trapping are given in Table 3.2. In all cases, ratels (*Mellivora capensis*), sand cats (*Felis margarita*) and African wild cats (*F. silvestris*) were tagged and released on site. All red foxes (*V. vulpes*) and feral cats (*Felis catus*) in all years, and all Rueppell's foxes (*V. rueppelli*) in 1997 were translocated more than 60 km from the reserve. Animals were translocated, not killed, because NWRC managers considered this to be more humane, and because it fitted with an unstated policy of managers to reintroduce houbara into the reserve without impacting on other native species that lived there. In other years, all Rueppell's foxes captured were released on site because local rangers and Olfermann (1996) did not consider that they were capable of catching houbara. Some red and Rueppell's foxes and feral cats in 1995 and 1996 were not tagged when tag supplies ran out. For each trapping session corrected trap nights (CTN) and captures per 100 CTN were calculated. CTN was calculated by subtracting 0.5 trap nights for every sprung trap and for traps that caught non-target species. Captures per 100 CTN were calculated by dividing the numbers of each predator caught by the CTN then multiplying the result by 100.

Table 3.2: Dates of opening of cage traps adjacent to the release enclosure, and the number of trap nights per year. Leg-hold and additional cage trapping data used in 1997 are also given. VR = *Vulpes rueppelli*, VV = *V. vulpes*, FC = *Felis catus*.

Year and trap type	Traps	Date opened	Date closed	Days open	Trap nights	How predators were handled
1995, cage	23	7 Feb	26 Oct	60	1380	VR, tag and release, VV, FC tag, translocate >60 km and release
1996, cage	23	10 Jan	23 Dec	189	5724	VR, tag and release, VV, FC tag, translocate >60 km and release
1996, leg-hold	24	13 May	28 May	13	312	VR, tag and release, VV, FC tag, translocate >60 km and release
1997, cage, Site 1	30	14 May	7 Jun	24	720	VR, VV, FC tag, translocate >60 km and release
1997, cage, Site 2	25	21 May	29 Jun	39	975	VR, VV, FC tag, translocate >60 km and release
1997, cage, Site 3	25	11 Jun	4 Jul	23	575	VR, VV, FC tag, translocate >60 km and release
1997, cage, Enclosure	23	9 Jul	6 Oct	93	2139	VR, VV, FC tag, translocate >60 km and release

Environmental data

Daily temperatures (mean, minimum, maximum) and total daily rainfall were measured at an automated climate station situated 200 m north east of the release enclosure fence. The station collated and stored continuous data every 15 mins. I calculated total rainfall for the one month period preceding each release, the highest maxima, and the mean daily maxima for one month after each release. I categorised moon phases into two groups of 14 nights duration: "moonlit" nights, and "no moon" nights. Moonlit nights were all nights from a waxing half moon to a waning half moon. No moon nights were those from the waning half moon to the next waxing half moon.

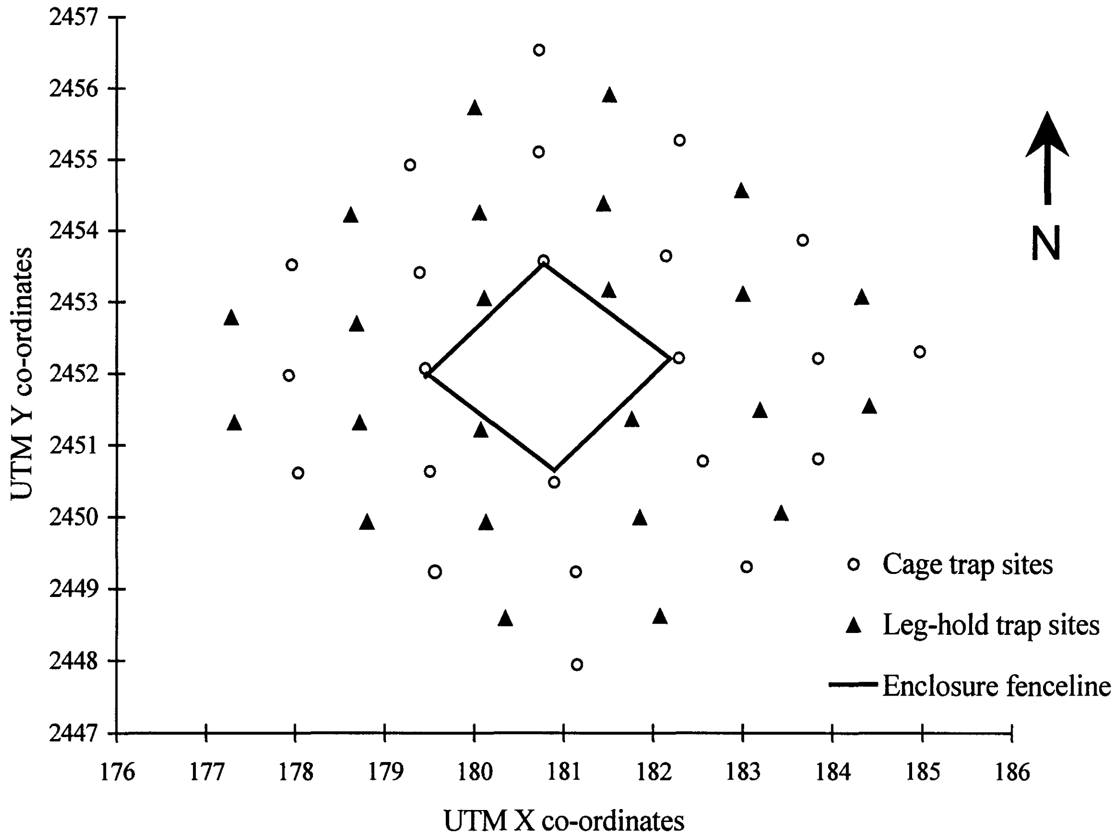

Figure 3.3: Location of cage and leg-hold trap sites adjacent to the release enclosure. See Table 3.2 for dates and number of trap nights that each trap type. UTM (Universal Transverse Mercator) is a world-wide rectangular metric co-ordinate system (White & Garrott 1990). Scale is in km. Mahazat as-Sayd Reserve lies on the boundary between UTM 37 & 38 grids.

Determining cause of death

Houbara are difficult to observe and catch in the wild (Seddon *et al.,* 1999), and therefore regular observations and health checks were not possible. Most dead birds found either had been killed or scavenged by predators, but were often little more than a pile of feathers and a chewed transmitter. Clearly, houbara that were caught by predators may have been suffering from other injuries, illness or starvation prior to capture. These underlying causes were not identifiable, and as such are likely to be under-reported in this study. In assigning causes of death I assumed that predation was the main cause of death whenever I found a body that showed signs of visitation by a predator. I did this because the signs at these remains were the same as in 23 cases for which predation was the definite cause, where I was able to locate tracks of predators and houbara and follow the entire hunting and attack sequence. I assigned a predator species to a predation event whenever possible. Predator species or type was determined by footprints of the predator, and bite and tear marks on the houbara's flesh. Rueppell's fox are smaller than most red foxes (Olfermann 1996), but, except for extremely large red fox tracks, I was unable to distinguish fox species by their footprints. Nor was it possible to separate wild cat from feral cat prints.

Success of releases

I used survival to one year of age as a measure of recruitment to the breeding population, because some wild and captive houbara have bred in their first year (Saint Jalme & van Heezik 1996, Gélinaud *et al.,* 1997, Chapter 4). Otherwise success is defined as persistence for two months after release. A two month period was selected because Combreau & Smith (1998) reported that most sub-adults died from predation within 54 days of leaving the enclosure.

Statistical comparisons

Because outcomes for released birds are not always known I used the Kaplan-Meier Product-Limit Method of survival analysis to generate and compare life table data (Kaplan-Meier 1958). Analyses were performed using the programmes Statistica (StatSoft 1995), and R. The survival analysis technique is commonly applied to medical and more recently biological datasets where individuals are present for some but not all of the period of interest. Mark-recapture type analyses could be applied, but because all released houbara had radio-transmitters, I was able to assign all birds to a fate category, and therefore there was no unknown population on which to apply mark-recapture statistics. Goodness-of-fit-type tests are not suitable because missing birds with unknown fates are excluded from comparisons. The advantage of survival analysis is that it allows missing cases to be included up to the day they go missing and thus valuable data are not lost. Missing houbara may be dead, have failed transmitters, or have dispersed widely. In addition, non-parametric statistical comparisons can be made in survival analysis using several complimentary methods. I used the Cox's F-test for comparisons of the two release sites because it is best for data sets with exponential distributions, when sample sizes are small (< 50 per group) and when there are few right censored observations (i.e., birds that survive to the end of the sample period; StatSoft 1995). Initially, 12 independent variables were considered for inclusion in a Cox Proportional Hazard model, a regression technique for survival data which is free from assumptions about the underlying survival distribution. The dependent variable was the fate (alive, dead) of released houbara at the end of each week following release for a period of two months, and data for independent variables were calculated for the same weekly periods. Two of the independent variables were discarded (rainfall in the 6 months prior to release because of incomplete records, and whether the bird was in the enclosure each week because this was closely correlated with release method). The other 10 variables run in the global model were: year of release, age at release, gender, release group size, release method, moon stage at release (as a % of a full moon), season of release (summer or autumn), mean daily maximum temperature for the one week after the release date then weekly thereafter, total cumulative rainfall during the 6 months prior to the release then calculated at the last day of each week thereafter, and moonlight per week calculated as a mean % of full moonlight for each week. Significant factors were then analysed separately, and the data grouped (stratified) by release method to assess effects while controlling for release method.

Results

Numbers of birds released

From 1995 to 1997, 162 sub-adult houbara were transported to Mahazat as-Sayd Reserve for release. Ten birds were injured in soft cages before release and were returned to the captive centre. The remaining 152 were released in one of 22 small groups either into the enclosure (N = 126), or into the reserve (N = 26; Table 3.3, Table 3.4). Twenty-one of the 126 birds released into the mammal-free enclosure died inside the enclosure; 105 flew from the enclosure into the reserve. Releases occurred during six months from May to November, with most birds (N = 128) being released during hotter months from May to July, compared to cooler and wetter months from August to November (N = 24, temperature and rainfall data given in Appendix 1).

Table 3.3: Summary of number, group size, timing, and release location for houbara released into Mahazat as-Sayd Reserve from 1995 to 1997.

		1995	1996	1997	Total
Total birds released		44	42	66	152
Group	Number of groups	10	6	6	22
	Mean group size	4.4	7.0	11.0	6.9
	Group size range	3 – 8	1 – 10	8 – 19	1 – 19
Timing of release	May – July	40	41	47	128
	August – November	4	1	19	24
Place of release	Into enclosure	44	42	40	126
	Into reserve	-	-	26	26

Survival of released birds

On 28 March 1998, at the end of the study, 31 (20 %) of the 152 birds released from 1995 to 1997 were still alive. Survival rates were low because in all years combined only 56 birds (37 %) survived the first two-month period after release. A total of 100 (66 %) of the birds that did not survive were found dead, and the remaining 21 (14 %) went missing with no indication of their fate (i.e, dispersed widely, transmitter failure or transmitter destruction during predation).

Survival was related to the release method used. Birds released directly into the reserve had a significantly lower probability of surviving for two months and for one year than did those released into the enclosure (Cox's F-tests; 2 months, $F_{(106,46)} = 2.22$, $P = 0.0016$; Fig. 3.4).

An analysis of the fate of released houbara against 10 independent variables was significant (Cox Proportional Hazard model, $R^2 = 0.043$, Likelihood ratio test = 35.9, d.f. = 10, $P < 0.0001$), but only the release method was a significant term within the model ($P = 0.0021$). Fitting a model using only release method as a risk factor was still significant ($R^2 = 0.033$, $P < 0.0001$). Then, because moonlight per week ($P = 0.16$) was the next closest term to being significant in the global model, a third model was fitted using only release method and moonlight per week; this model was also significant ($R^2 = 0.039$, $P < 0.0001$). To gauge the effect of moonlight for each of the two release methods, a fourth model was then fitted with release method as a stratifying factor, and moonlight as a risk factor. In this model, the effect of moonlight remained a significant factor, with released houbara having a lower chance of survival on nights with more moonlight ($R^2 = 0.006$, d.f. = 1, $P = 0.025$). A comparison of the third and fourth models using a partial likelihood ratio test determined that the stratified (fourth) model was the better fit (d.f. = 1, $P < 0.001$). This was explored further by including the variable representing time spent in the enclosure as a risk factor in a model, with moonlight as a covariate, and release method as a stratifying variable. As a result, both moonlight and time in the enclosure were identified as significant variables ($R^2 = 0.075$, d.f. = 2, $P < 0.0001$), where houbara were more likely to survive on darker nights, and when inside the enclosure. However, the interaction between time spent in the enclosure and moonlight was not significant ($P > 0.05$).

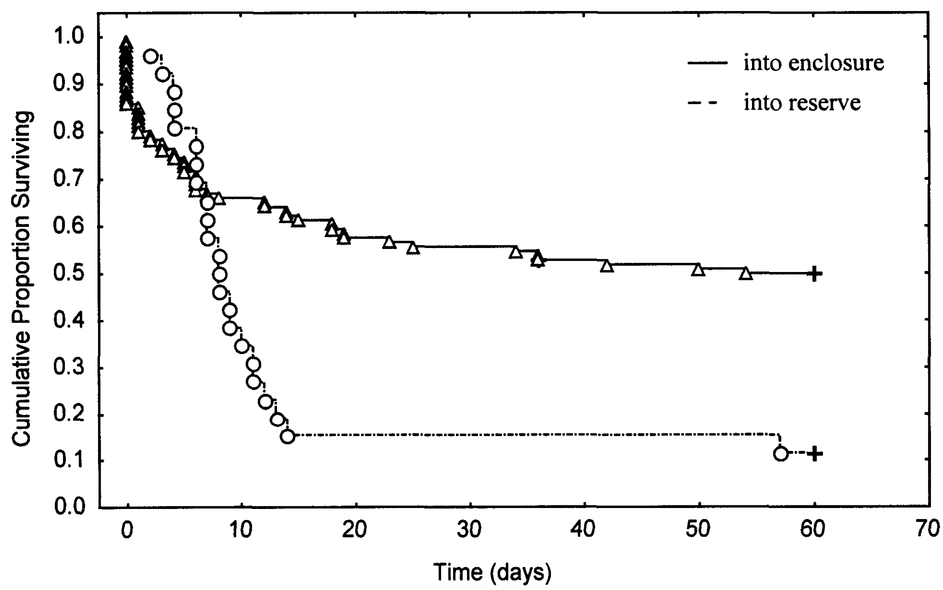

Figure 3.4: *Effect of release site on mortality rate:* Kaplan-Meier Product-Limit survival analysis curves of the cumulative proportion of houbara surviving for two months from those released into the enclosure or directly into Mahazat as-Sayd Reserve from 1995 to 1997. Open circles and triangles = deaths, + = missing birds.

Table 3.4: Number of birds that were released inside the enclosure or directly into Mahazat as-Sayd Reserve (Sites 1 – 3) from 1995 to 1997, and their fate. Missing birds were those for which a radio signal was lost and the bird or its body could not be located.

Year & group number	Date of release	Location of release	Number released	Died in enclosure	Died in reserve	Missing	Alive at 28 March 1998
95_1	28-May-95	Enclosure	4	0	0	3	1
95_2	05-Jun-95	Enclosure	8	1	3	3	1
95_3	15-Jun-95	Enclosure	3	0	2	1	0
95_4	20-Jun-95	Enclosure	6	1	2	2	1
95_5	29-Jun-95	Enclosure	4	0	4	0	0
95_6	20-Jul-95	Enclosure	3	0	1	2	0
95_7	13-Aug-95	Enclosure	5	2	2	1	0
95_8	18-Aug-95	Enclosure	3	0	3	0	0
95_9	23-Aug-95	Enclosure	4	0	2	1	1
95_10	02-Oct-95	Enclosure	4	0	1	2	1
96_1	02-Jun-96	Enclosure	8	0	4	2	2
96_2	23-Jun-96	Enclosure	10	2	6	1	1
96_3	08-Aug-96	Enclosure	10	1	4	0	5
96_4	12-Aug-96	Enclosure	8	1	6	1	0
96_5	14-Aug-96	Enclosure	5	2	1	1	1
96_6	11-Oct-96	Enclosure	1	1	0	0	0
97_1	11-Jun-97	Reserve S1	8	-	8	0	0
97_2	22-Jun-97	Reserve S2	8	-	8	0	0
97_3	29-Jun-97	Reserve S3	10	-	10	0	0
97_4	18-Jul-97	Enclosure	9	1	3	0	5
97_5	22-Jul-97	Enclosure	12	6	3	0	3
97_6	01-Nov-97	Enclosure	19	3	6	1	9
Total enclosure			**126**	**21**	**53**	**21**	**31**
Total reserve			**26**	**-**	**26**	**0**	**0**
Grand total			**152**	**21**	**79**	**21**	**31**

Recruitment rates (the proportion of birds released surviving on 1 March of the following year) were similar in all three years, with a mean of 27 % of released sub-adults surviving to potential breeding age (Table 3.5).

Table 3.5: Number (%) of sub-adult houbara recruited into the breeding population in each year from 1995 to 1997. Successful recruitment was defined as houbara that survived to 1 March of the year following release. Most released birds were approximately one year old at this time and can potentially breed.

	Recruited into breeding pool		
Year	No	Yes	Total released
1995	31 (70.5)	13 (29.6)	44
1996	31 (73.8)	11 (26.2)	42
1997	49 (74.2)	17 (25.8)	66
Total (Mean %)	111 (73)	41 (27)	152

Cause of mortality

From 1995 to 1997, 100 of 152 (66 %) birds released were confirmed dead (Table 3.6). Twenty-one (14 %) of these deaths occurred in the mammal-free enclosure before birds flew out into the reserve. Of these, two birds hit the fence, four died from starvation, two from aerial predators, one from an unknown predator, and the remaining 12 died from unknown causes but not from predation. In contrast, 76 (96 %) of 79 deaths outside the enclosure were assigned to predators, and only three to non-predators. Cause of death was confirmed in 26 cases; 21 (81 %) were foxes, 2 (8 %) were avian predators, 2 (8 %) were cats, and one was killed by a human. However, in 51 cases, predators could not be identified. Frequently, chewed transmitters (indicating a mammalian predator), feathers and occasionally buried remains were found, with no tracks in the vicinity. In these cases, predation was assumed as the cause of death, but some birds may have been scavenged after dying of other causes. Sand tracking was only possible in sandy and silty sites, and usually indicated that houbara were walking slowly prior to detection by the predator, then ran for a short period (< 20 m) prior to capture. Deaths that occurred on rocky outcrops, or in dense vegetation could not be tracked, and therefore few data on the behaviour (e.g., roosting / feeding) of houbara prior to capture could be gathered.

Table 3.6: Fate as at 28 March 1998 of all houbara released from 1995 to 1997.

Fate	1995	1996	1997	Total	% of total
Alive	**5**	**9**	**17**	**31**	**20.4**
Missing	**15**	**5**	**1**	**21**	**13.8**
Died inside enclosure					
Hit enclosure fence	1			1	0.6
Non-predation	3	6	9	18	11.8
Avian predation		1	1	2	1.3
Total dead in enclosure	**4**	**7**	**10**	**21**	**13.8**
*Died outside enclosure**					
Non-predation			2	2	1.3
Avian predation			2	2	1.3
Predation by cats		1	1	2	1.3
Predation by foxes	2	5	14	21	13.8
Predation – predator type unknown	17	15	19	51	33.6
Killed by humans outside reserve	1			1	0.6
Total dead outside enclosure	**20**	**21**	**38**	**79**	**51.9**
% all deaths by predation	**43 %**	**52 %**	**56 %**		**51 %**
Grand Total	**44**	**42**	**66**	**152**	

* includes 26 birds released in directly into the reserve in 1997

A further 21 birds went missing. It was unknown what proportion of these died or dispersed away from the reserve, and both scenarios are equally possible. Buried and damaged transmitters (aerials removed) were detected for a few dead houbara, but signal range was less than about 200 m on the ground and 500 m from the air, and detection was by chance. If transmitters were destroyed during predation events, then it is unlikely that bodies would be found. Similarly, many houbara dispersed quickly away from the enclosure, and some travelled 20 – 40 km from the release site overnight. Houbara that flew more than 150 km beyond the reserve boundary to the north, east and south, or more than 250 km to the west (i.e., the extent of aerial searches), were unlikely to be detected.

Location of mortality events

Most houbara died close to the release site after moving in random directions away from the site (Fig. 3.5). There were no differences among years (Kruskal Wallis test, $H = 4.58$, $P > 0.05$), or release sites ($H = 4.47$, $P > 0.05$) in the distance from the release to death site (Fig. 3.6). Overall, mean distance from release site to death site was 3.4 ± 2.8 km (mean ± 95 % C.I.) for enclosure releases and 4.1 ± 3.2 km for releases directly into the reserve. In total, 64 % of houbara that flew from the enclosure died within the 2 km radius trapping grid around the enclosure, and 62 % of houbara died within the 2.5 km grid around the reserve release sites (Fig. 3.7).

Age of released birds and time to death

Sub-adults were a mean of 96 days old (95 % C.I. = 89 – 102) when released. Released birds were 19 – 21 days younger in 1995 and 1996 than in 1997, but this age difference was not significant (Kruskal Wallis Test, $P > 0.05$; Table 3.7a). Once released sub-adults spent between 0 and 147 days ($\bar{x} = 26$ days, 95 % C.I. = 17 – 35) in the release enclosure, and this was significantly less in 1997 ($\bar{x} = 8$ days) than in previous years ($\bar{x}$ = > 30 days; K-W Test, $H = 8.39$, $P = 0.015$, Table 3.7b). Mean age at death was 136 days (95 % C.I. = 125 – 147), and ages at death were similar between years (K-W Test, $P > 0.05$, Table 3.7c). There was no relationship between age at release and age at death for houbara released into the enclosure in any of the three years (Pearson's Product-Moment correlation, for all years: $r^2 < 0.08$, $P > 0.05$, $N = 126$). The oldest bird released from 1995 to 1997 that died was 317 days, the youngest was 71 days. Mean time from release to death was 39 days (range 2 – 228). Time to death was strongly left-skewed; 50 % of deaths occurred within 14 days of release and 75 % were dead within 51 days. For sub-adults that flew from the enclosure, those that lived did not spend more time in the enclosure than did those that died (Two sample T-test, $P > 0.05$, missing birds excluded, Table 3.7d). Mean time to death after leaving the enclosure was 23 days (95 % C.I. = 13 – 33), with no differences between years (K–W Test, $P > 0.05$, Table 3.7e).

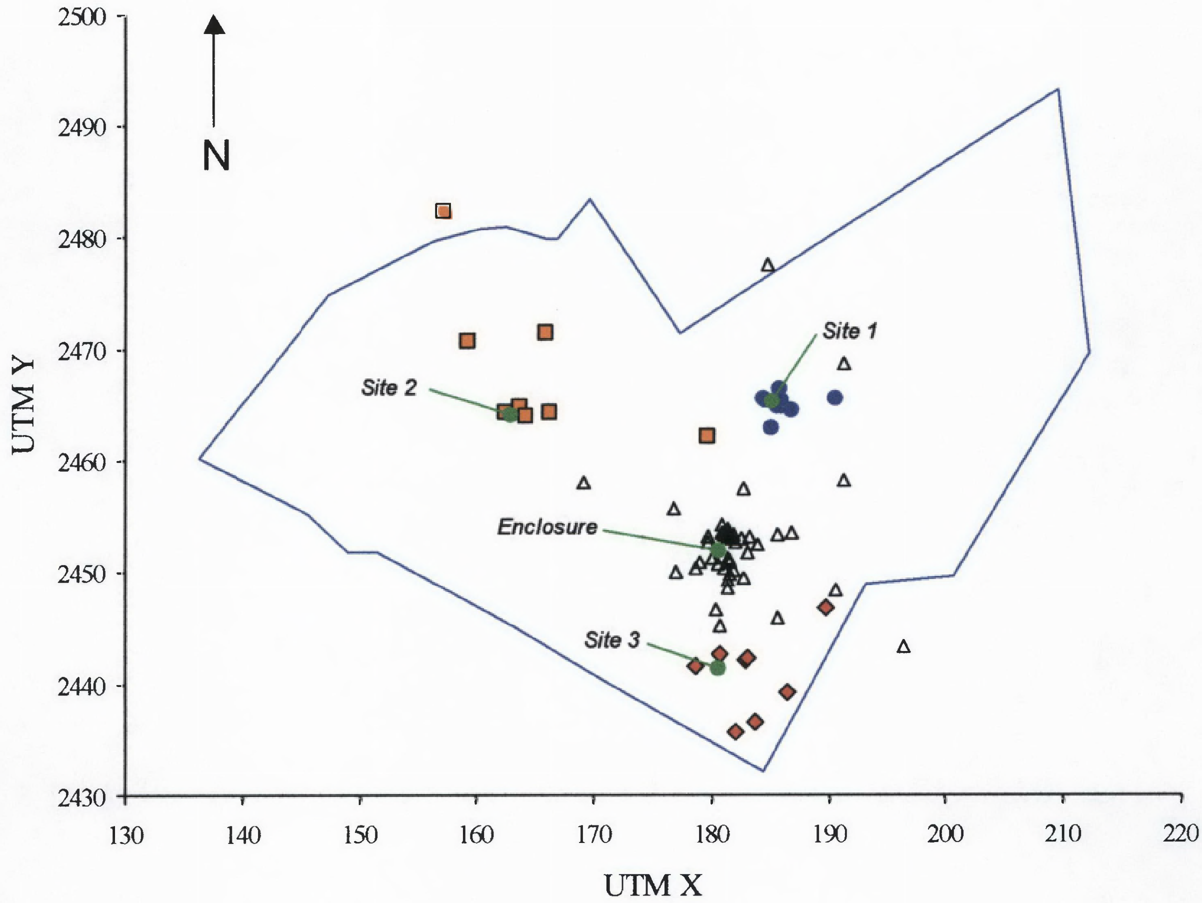

Figure 3.5: Location of release sites (green circles) and sites where released houbara were found dead: released from enclosure (open triangles), Site 1 (blue circles), Site 2 (orange squares), and Site 3 (red diamonds). UTM co-ordinates and scale as for Figure 3.3. The solid line is the Mahazat as-Sayd Reserve boundary fence.

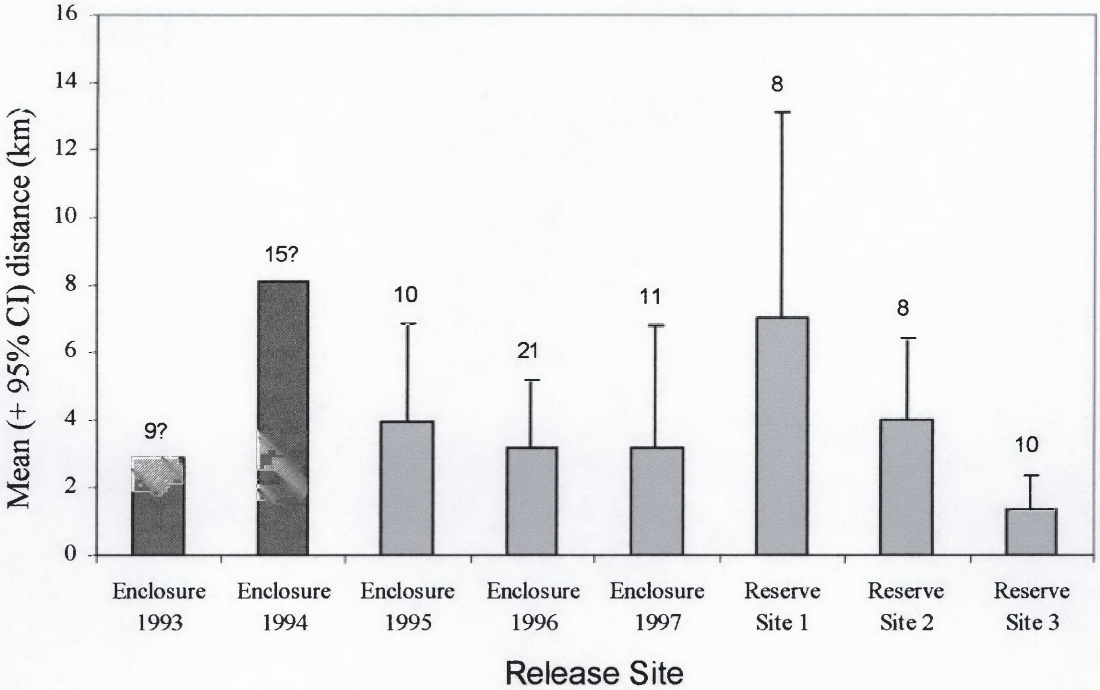

Figure 3.6: Mean (+ 95 % C.I.) distance between release site and where houbara were killed. Predator control occurred in all years and sites except for 1993. All releases into "Reserve Sites" were in 1997. Data for 1993 and 1994 (black bars) are from Combreau & Smith (1998). Numbers above bars are sample sizes.

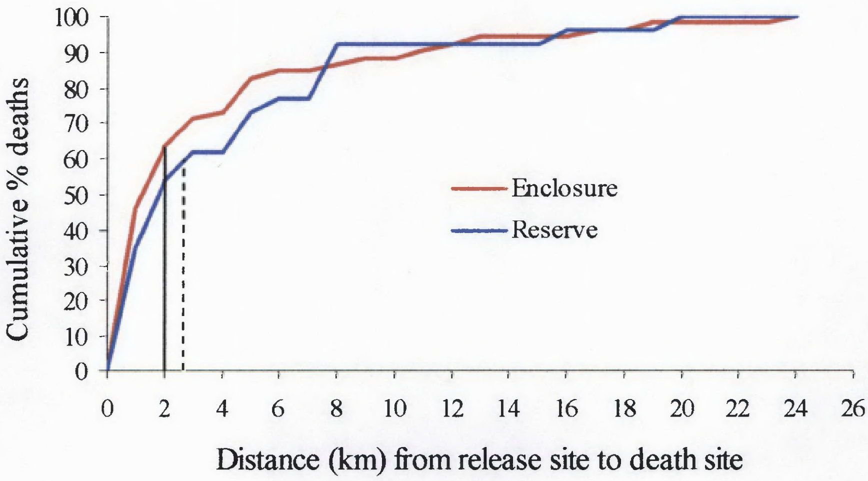

Figure 3.7: Cumulative proportion of birds that died related to the distance of the site of death from the release site, for houbara released into the enclosure from 1995 to 1998, and for those released into the reserve in 1997 (N= 26), and enclosure (N = 53, excludes birds that died in enclosure). Vertical lines are the outer limit of predator trapping around enclosure (solid line) or reserve sites (dotted line). All points to the left of these lines are the proportions of houbara deaths that occurred within predator control grids.

Table 3.7: Mean ± 95 % C.I., minimum and maximum (a) age at release, (b) number of days from release to leaving the enclosure, (c) age at death, (d) days from release until death, and (e) days from leaving enclosure until death, of all sub-adult houbara released into Mahazat as-Sayd Reserve from 1995 to 1997, for which bodies were found. N values are 24, 28 and 48 for 1995, 1996, 1997, respectively, except for (b) where N = 20, 21, 12.

	1995	1996	1997	All years
(a) Mean age of birds at release	87	85	106	96
± 95 % C.I.	76 – 97	79 – 91	94 – 119	89 – 102
Range	59 – 167	57 – 110	74 – 226	57 – 226
*(b) Mean number of days from release to leaving enclosure**	33.0	30.6	7.9	26.0
± 95 % C.I.	18 – 48	12 – 50	3 – 13	17 – 35
Range	6 – 120	2 – 147	0 – 25	0 – 147
(c) Mean age of birds at death	141.7	125.2	139.6	136.1
± 95 % C.I.	121 – 162	109 – 142	121 – 159	125 – 147
Range	81 – 279	71 – 215	78 – 317	71 – 317
(d) Mean days from release to death	51.1	38.3	33.2	38.9
± 95 % C.I.	31 – 71	23 – 53	17 – 49	29 – 49
Range	6 – 209	4 – 145	2 – 228	2 – 228
*(e) Mean days from leaving enclosure to death***	24.0	6.7	31.0	22.9
± 95 % C.I.	2 – 46	2 – 11	13 – 49	13 – 33
Range	0 – 195	0 – 36	0 – 228	0 – 228

*includes only those birds released into the 400 ha enclosure, and excludes all 26 birds released into the reserve in 1997.

** includes all 1997 birds in Groups 1 – 3 that were released into the reserve, so therefore left their enclosure on the day of release.

Captures of predators

Six species of mammalian predator were caught in cage traps between 1995 and 1997 (Table 3.8). Cats and ratels were rarely caught, and most of the 366 individual predators caught were red (40 %) or Rueppell's foxes (56 %). Individual Rueppell's foxes that were not translocated were recaptured a mean of 3.5 times (range 1 – 52) over the three year trapping period around the enclosure. Capture rates were very high in most sites due to recaptures of Rueppell's foxes. Thus in 1996 at the enclosure site, only 2.29 predators per 100 CTN were caught, because 3 – 10 times as many trap nights were used, and predators were translocated away from the trapping site. Absolute capture rate of individuals was highest in 1996, and 57 % of all predators caught around the enclosure were caught in that year (Table 3.9). A total of 138 red and 81 Rueppell's foxes were translocated. Those Rueppell's foxes not translocated were released on site; red foxes not translocated were humanely killed. Two wild cats, one feral cat, two ratels, 20 red foxes, and nine Rueppell's foxes were released without ear tags. All non-tagged red foxes and the feral cat were translocated more than 60 km from the reserve, whereas all other non-tagged mammals were released on site. Three of five feral cats captured were translocated; all other cats and all ratels were released on site.

There were 34 captures of 23 individuals of the two fox species in leg-hold traps in 1996 (Table 3.8). Of the 14 adults and one juvenile Rueppell's fox caught in leg-hold traps, only the juvenile had not been previously caught in cages. Two of four adult red foxes caught in leg-hold traps were recaptures that had been caught in cage traps in previous sessions and released on site (Table 3.9). One of these foxes weighed 4.5 kg (1.6 kg more than mean fox weight in the reserve, Olfermann 1996). The two other red fox adults and four juveniles also caught were not ear-tagged and their history is unknown.

Thirteen red foxes that had previously been caught and tagged were later recaptured during cage or leg-hold trapping at houbara release sites (Table 3.9). At least three foxes returned to the enclosure site after being translocated distances 45, 50, 70, and 140 km from the reserve. One red fox was caught and translocated twice, before being caught in the trapping grid for a third time. For each of these distances, the numbers of days before foxes returned and were caught were 89, 14, 16 and 347 days, respectively. Six of the red foxes were recaptured during extra cage trapping during September to November in 1996, a period of year when little previous trapping had occurred.

Table 3.8: Total number of mammalian predators, and number of individuals captured during trapping at houbara release sites, and the number of predators translocated from these sites, from 1995 to 1997. Total numbers of trap nights at each site and treatment of each species is given in Table 3.2. Non-target species are included in the sprung trap column and were brown-necked ravens, lizards, and snakes.

	Red fox	Rueppell's fox	Feral cat	Wild cat	Sand cat	Ratel	Sprung traps	Total captures	CTN	Captures per 100 CTN
Number of captures										
1995 Enclosure	24	359	4	0	0	0	20	387	1370	28.25
1996 Enclosure	52	246	0	5	2	2	66	307	5707.5	5.38
1996 Leg-hold	8	26	0	0	0	0	12	34	306	11.11
1997 Site 1	15	14	0	0	0	0	15	29	712.5	4.07
1997 Site 2	9	15	2	2	0	0	18	28	966	2.89
1997 Site 3	22	17	0	0	0	1	17	40	566.5	7.06
1997 Enclosure	21	32	0	0	1	0	23	54	2127.5	2.54
Total captures	**151**	**709**	**6**	**7**	**3**	**3**	**171**	**879**	**11756**	**7.48**
Number of individuals caught										
1995 Enclosure	21	40	3	0	0	0	-	64	1370	4.67
1996 Enclosure	51	71	0	5	2	2	-	131	5707.5	2.29
1996 Leg-hold	8	15	0	0	0	0	-	23	306	7.51
1997 Site 1	15	14	0	0	0	0	-	29	712.5	4.07
1997 Site 2	9	15	2	0	0	0	-	26	966	2.69
1997 Site 3	22	17	0	0	0	1	-	40	566.5	7.06
1997 Enclosure	20	32	0	0	1	0	-	53	2127.5	2.49
Individuals caught	**146**	**204**	**5**	**5**	**3**	**3**	**-**	**366**	**11756**	**3.11**
Number of individuals translocated										
1995 Enclosure	21	3	3	0	0	0	-	27	-	-
1996 Enclosure	51	0	0	0	0	0	-	51	-	-
1996 Leg-hold	4	0	0	0	0	0	-	4	-	-
1997 Site 1	15	14	0	0	0	0	-	29	-	-
1997 Site 2	9	15	0	0	0	0	-	23	-	-
1997 Site 3	20	17	0	0	0	0	-	37	-	-
1997 Enclosure	18	32	0	0	0	0	-	50	-	-
Total translocated	**138**	**81**	**3**	**0**	**0**	**0**	**-**	**222**	**-**	**-**

Table 3.9: Details of red foxes previously tagged and released on site, or translocated, that were recaptured at one of four sites in Mahazat as-Sayd Reserve. Other recaptures before 1 July 1995 may have occurred, but data were unavailable. All first captures were in cages. Translocated (Trans) = distance in km and direction (compass bearing) of translocation of foxes. Distances are straight-line minima. ROS = released on site. Tag colours are: Gn = green, P = pink, Y = yellow, B = blue, W = white, Gy = grey, R = red.

Tag	First capture	Trans	First recapture	Trap type	Trans	Second recapture	Trans	Third recapture	Trans
46GnP	17-Jun-92	ROS	21-Jul-96	Cage	70, S	06-Aug-96	125, SW		
51GnP	06-Jul-92	ROS	09-Aug-96	Cage	70, S				
108GnP	23-Oct-92	ROS	20-May-97	Cage	125, SW				
115GnP	21-Dec-92	ROS	28-May-96	Leg-hold	125, SW				
118GnP	11-Feb-93	ROS	26-May-96	Leg-hold	125, SW				
145GnP	12-Apr-93	ROS	24-Oct-96	Cage	125, SW				
146GnP	12-Apr-93	ROS	06-Nov-96	Cage	125, SW				
188GnP	03-Jun-93	ROS	01-Nov-96	Cage	125, SW				
228GnP	07-Aug-93	ROS	29-Apr-95	Cage	45, SE	27-Jul-95	50, SW	10-Aug-95	70, S
284GnP	08-Dec-93	ROS	20-May-97	Cage	Euthanased				
38YB	20-Oct-94	ROS	25-Oct-96	Cage	125, SW				
103WGy	24-Sep-95	140,SW	05-Sep-96	Cage	95, SE				
116R	15-Oct-96	Escaped	10-Nov-96	Cage	95, SE				

Discussion

Success of releases and causes of mortality

Release protocols used from 1995 to 1997 in Mahazat as-Sayd Reserve have resulted in the successful establishment of adult houbara in the reserve. About one quarter of all released houbara were recruited into the breeding population, and one fifth survived for one to three years after release. After houbara were released, the pattern of survival was clearly defined, and was similar in all three years of release. Most sub-adults either died within 50 days of release, or they lived to the end of the study period. They were more likely to die during a period of moonlight soon after they left the enclosure. Predators killed most birds for which a cause was assigned, and foxes were the primary predators identified.

The implication of this result is that houbara were susceptible to predation mostly during moonlit periods. The critical period of vulnerability was the first moonlit period when houbara were exposed to mammalian predators, although some deaths were recorded during later moonlit periods. Houbara are known to be more actively feeding during periods of moonlight than during dark inter-moon phases, particularly during summer months when daytime temperatures are usually over 40 °C (Anegay 1994, Combreau & Launay 1996, Appendix 1). Foxes too are more active during these periods (Olfermann 1996). Combreau & Smith (1998) suggested that moonlit periods were the times when the likelihood of encounter between predators and houbara was the greatest, and when the detection ability of houbara by foxes is maximised. However, this explanation is simplistic and does not explain why only initial moonlit encounters are important. My results strongly suggest that either (1) houbara are learning about predators and how to survive encounters during their first interactions, or that (2) straight after release, some houbara behave in ways that increase or reduce their vulnerability to predators. Possibly, the survivors are houbara that never feed in densely vegetated sites where foxes regularly occur, or always roost in open sites where fox visits are rare. Houbara are able to learn about foxes and this can have survival benefits (van Heezik *et al.,* 1999). Detailed micro-habitat studies of houbara movement at night, or evidence that some houbara actually encounter foxes and survive are required to determine the exact nature of the survival mechanism involved. Alternatively, releases in winter when conditions are cooler and houbara are spending more diurnal hours feeding, will reduce the probability of encounter between nocturnally active foxes and houbara during the initial post-release period. However, if houbara do survive via a learning process then releases at this time of year will delay the timing of mortality events until first encounters occur, but will not change the proportion of losses.

Released birds are potentially exposed to different climatic regimes, different and uncertain food resources, and to predators. Therefore, periods of time in controlled environments that allow birds to adapt to their new environment should be advantageous. The mammal-free enclosure was designed to provide such an environment, and birds that spent more time inside the enclosure did have a greater probability of survival. Possibly, this may be because staying in the enclosure for a period of time gets the bird past a stressful release period, and allows more time for adjustment to its new environment. As only fit birds had the strength to leave the enclosure, they may therefore have also had the strength and agility to be able to avoid predators. However, there may have been differences in the availability of food and in predation pressure at the release site and in other sites affecting predator numbers and hunting methods, that over-ride any differences among released birds. Thus, predicting the best strategy for a newly released houbara will be difficult: in some years the best strategy may be to stay, and in others to leave the enclosure.

Continued trials should focus on holding houbara for longer inside the enclosure, and releasing them only when food and weather conditions are optimal (presumably when it is relatively cool and wet), and when predation pressure may be reduced (e.g., outside the spring-summer period when foxes are breeding and require more food resources), thereby controlling for food, climate, and predator-related effects. Holding birds longer may have a mortality cost. A total of 6 % of houbara died in "soft" cages at the release site before they were due for release. A better design of cage, perhaps much larger to prevent injury during the pre-release acclimatisation phase, is suggested. Generally, a pre-release holding period has not been a defining characteristic in successful reintroduction projects. Of 65 release projects for 54 species of birds, 83 % used some form of acclimatisation period (Beck *et al.*, 1994), but while 75 % of successful projects (defined as 500 individuals free of human support, or viability modelling to show self-sustainment, Beck *et al.*, 1994, p. 273) had acclimatisation, so did 68 % of unsuccessful projects. For houbara releases in Mahazat as-Sayd Reserve, pre-release losses have been relatively low, but the risk of holding birds in cages for long periods of time has to be balanced against potential gains in future survival once released.

Importance of predator control

My results show that the levels of predation following release were similar to those of Combreau & Smith (1998) from 1993 and 1994. Over the entire five year period from 1993 to 1997 annual predation rate varied only 11 % (from 43 – 54 %). Predation rates remained high in all years, despite an intensification of trapping around the release sites. Contrary to Combreau & Smith's (1998) result that predator trapping increased the distance to death sites and time alive prior to death, there was no evidence that predator trapping achieved any form of protection of houbara from 1995 to 1997. Survival time and distance to death from 1995 to 1997 were very similar to those in 1993, when no predator trapping occurred (see Fig. 3.6), and thus the 1994 result of Combreau & Smith (1998), that trapping increased the distance to death sites and time to death, should be seen as a one-off occurrence. A caveat to this conclusion is that no control group or replication was used in any of these years, except for releases outside the enclosure in 1997, and thus comparisons are limited to between year and site differences. Two extra areas of research are required. First suitable controls, such as direct release into the reserve without predator control, are required for future houbara release trials, despite the potential for high mortality of birds in the control group. Second, better baseline data from wild populations are needed, to provide details on survival and recruitment rates for wild-born juveniles (see chapter 4). Without adequate controls and baseline data, survival data for released houbara, and the relative merits of alternative release techniques will be difficult to evaluate.

Why was predator control apparently ineffective? There are three explanations why predator control may have failed to protect houbara after release. First, some houbara may be pre-disposed to predation, because they behave inappropriately or because they have other illnesses or conditions, which increase their vulnerability. For example, kaki (*Himantopus novaezelandiae*) have been captive-reared and released in New Zealand each year since 1993. From 1993 to 1997 most causes of death of released were assigned to predators, but since the addition of iodine to the captive diet prior to release to prevent goitre, and provision of supplementary food after release in 1998, very few predator-related deaths have been recorded. The conclusion was that supplementary food, and iodine, increased the health of the released birds, and fit healthy birds were less vulnerable to predation (unpubl. data). There is some evidence that the health of houbara immediately after release was poor. Within the release enclosure, in the absence of mammalian predators, 18 birds died from non-predation causes (excluding one that hit the fence), but only two non-predator causes of deaths were recorded outside the enclosure. There are two explanations for this pattern. Either birds were slow to adapt to the conditions at the release site, and were weak and sick and died before leaving the enclosure – thus only fit birds flew over the 2 m high fence into the reserve. Alternatively, once in the reserve, predators quickly captured weak and sick birds, or scavenged bodies, and therefore their fate was recorded as predation, when predators were not primarily implicated.

Second, predator control may have been ineffective because translocation was an ineffective tool. Translocation may have exacerbated predation levels at release sites, because animals returned to the release site and they may have subsequently become harder to trap (cryptic predator effect). Translocation distances in 1994 were short; frequently predators were not even removed outside the reserve boundaries, and some were known to have returned to the trapping grid (Combreau & Smith 1998). Although I used longer translocation distances for predators, one fox returned from 140 km, the furthermost translocation distance that was practical to use. Recaptures of red foxes in cage traps are not common (Olfermann 1996, Lenain 1997), indicating an increased wariness after initial capture. Using an alternative trapping technique and increasing the intensity of cage-trapping I caught 13 red foxes that had been previously caught in the trapping grid, at least three of which had been previously translocated. Most of these were first caught between 1992 and 1994, and may have been present as part of a cryptic population of previously captured predators around the release site ever since.

Third, control may have been ineffective because predators other than red foxes may have been killing houbara. I concur with Combreau & Smith (1998) that it is unlikely that sand cats or ratels were the primary predators of released houbara. None of the intensive foot tracking I did indicated that these predators were implicated in any houbara death, and both species are apparently rare within the reserve. Feral or wild cats were responsible for at least two houbara deaths, but again both are uncommon. It is less certain whether Rueppell's foxes are major predators of houbara. Rueppell's foxes were the most common mammalian predators in the reserve, they were frequently caught and released at capture sites, and I was unable to distinguish their tracks from those of red foxes. The conclusion that Rueppell's foxes could not be major predators of houbara because they are small, mainly insectivorous, and were present adjacent to the enclosure in 1994 when predation rates declined (Combreau & Smith 1998) seems tenuous. Released houbara weighed 700 – 1200 g, less than both Rueppell's foxes (~1.6 kg) and red foxes (~2.9 kg). Rueppell's foxes are generalist not specialist predators; insects make up around 50 – 60 % of their diet, the rest are other taxa, including small mammals, lizards and birds (Olfermann 1996), and the decline in predation around the enclosure observed in 1994 was not sustained in any year from 1995 to 1997. If houbara were weak or sick following release then Rueppell's foxes may have easily caught and killed them. I suggest that further evidence of the relative role of red and Rueppell's foxes as predators of houbara is required before Rueppell's foxes are excluded as potential predators.

Finally, predator control in the 32 km^2 area surrounding the release enclosure may actually have been very effective in reducing predation rates, especially if the proportion of weak or sick birds was different in different years. Because there were no within-year controls of the predator trapping regime (i.e., sites with and without predator control) then predators may have differed both numerically (change in abundance or distribution) or functionally (diet switching) between years. I did not attempt to test either of these scenarios. Although capture rates and absolute numbers of predators caught differed among years and sites, relative capture rates could not be determined because there was no standardisation of trapping effort. Even with equal effort, potential differences in trapability of predators between years would reduce the value of these data. Determining whether prey-switching by predators occurred that may have intensified or reduced predation rates on houbara would require knowledge of the diet of predators and the relative abundance of predators' prey at all times of year, at the release site and in other sites where predators may travel.

An alternative approach to predator control is to teach houbara to recognise and respond appropriately to predators. Pre-release training has not been a common factor in successful releases of animals (Beck *et al.,* 1994), but because reintroduction projects often use captive-bred and reared stock, then intuitively stock for release will be naive about the post-release world they are about to enter. As such, the benefits of suitable pre-release preparation should be very real. Methods for training animals to modify their behaviour towards predators have been successfully developed (Miller *et al.,* 1990, Maloney & McLean 1995, McLean *et al.,* 1996). We have shown elsewhere (van Heezik *et al.,* 1999) that exposing naive sub-adult houbara to a live red fox prior to release increases their post-release survival chances when compared to untrained control birds, and thus training may offer a real alternative to continued predator control. However, despite this apparent success, the overwhelming observation is that most houbara released into Mahazat as-Sayd Reserve died soon after release, regardless of the pre-release preparation the birds received.

Alternative release sites

I predicted that releasing houbara in sites away from the enclosure would result in higher survival rates, because predators would be less wise to their presence. This prediction was not supported. Houbara released in three sites in the reserve in 1997 had much lower chances of survival than those released in the enclosure. Although most houbara released into the enclosure flew from the enclosure soon after release and were effectively exposed to the same release conditions as those that were released directly into the reserve, the fence may have acted like a filter because houbara had to be fit enough to fly over this barrier and enter the reserve. Thus, some weak birds in the enclosure may not have been initially exposed to predation until their condition improved. It may be simply that individual houbara require different amounts of time to adjust to conditions after release, and that all birds are at risk from predators at some stage after release. This is supported by the observation that all birds were released on dark moonless nights, and therefore regardless of whether they were released into the reserve or enclosure they had several days to adjust to wild living before encountering foxes during moonlit periods, and yet many birds released in both the enclosure and reserve were eventually killed by predators. Sites of releases into the reserve were subjectively chosen because they were greener, with better potential food supplies than most of the rest of the reserve. Possibly, these sites may have been focal points for predators as well, but this seems unlikely as predator capture rates were not higher than around the enclosure (Table 3.8), predators are territorial and should actively exclude other predators from their ranges, and predators continued to be caught in other reserve locations that were noticeably dry (Lenain 1997). Nor were temperature or rainfall significant factors in the observed differences between reserve and enclosure releases. Conditions during reserve releases in June and July 1997 were hot and dry, but this is normal in every summer, throughout the reserve. Temperature and rainfall conditions experienced by houbara that died were not different from those experienced by those that survived.

Despite the apparent failure of releases into the reserve, further experimentation with releases in other sites away from the enclosure is warranted, for four reasons. First, the enclosure was costly to build and is not transportable, and using such a method will hinder future releases in other reserves if resources are limited. Second, a fixed release site does not allow the flexibility to choose release sites based on food availability, habitat conditions (e.g., potential breeding sites), presence (or absence) of resident houbara, or predator densities. Habitats where houbara naturally occur are very patchy environments, and mobile release sites should maximise opportunities to release and establish houbara at many sites. Third, a single large fixed enclosure site limits the ability of researchers to experiment with release methods and release sites, and limits predictions about general houbara ecology and behaviour that can be tested using releases in different habitats. Fourth, because managers have invested heavily in enclosure construction, then there is a tendency to use such sites and then try to correct failings associated with it (e.g., undertaking predator control) rather than selecting and experimenting with sites or times where factors may be inherently better for houbara (e.g., places where fox densities are naturally low).

In conclusion, houbara releases into Mahazat as-Sayd Reserve have been successful in that released birds have persisted, and later bred (Chapter 4). Survival rates have been low because houbara were killed soon after moving into the reserve on moonlit nights. Initial trends from releases prior to this study have not been fully supported with three further years of data and the need to have a long-term approach to release research is emphasised. Because not all houbara survived the release process, there is still much to be gained from experimenting with new release methods, despite the apparent failure of releases directly into the reserve as used in 1997. I suggest radically different approaches to the current release format are warranted, such as total predator eradication at release sites to allow weak birds time to adjust, the development of mobile release techniques, and releases in winter when climatic conditions are more favourable, if advances in our understanding of houbara reintroduction are to be made.