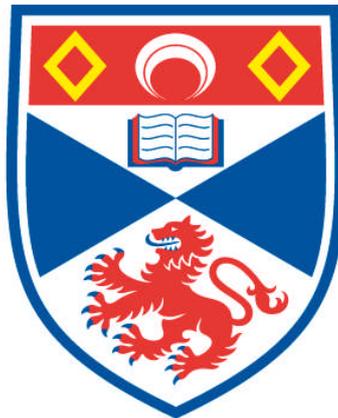


**DEVELOPING AND ASSESSING A POPULATION MONITORING  
PROGRAM FOR DORCAS GAZELLE (GAZELLA DORCAS) USING  
DISTANCE SAMPLING IN SOUTHERN SINAI, EGYPT**

**Husam E. M. El Alqamy**

**A Thesis Submitted for the Degree of MPhil  
at the  
University of St Andrews**



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# **Developing and Assessing a Population Monitoring Program for Dorcas Gazelle (*Gazella dorcas*) Using Distance Sampling in Southern Sinai, EGYPT**

Husam E. M. El Alqamy



Thesis submitted for the degree of

**MASTER OF PHILOSOPHY**

In the School of Biology  
Division of Environmental & Evolutionary Biology

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## *Abstract*

A monitoring programme to provide information about the dorcas gazelle population in two regions (the Qa'a plain and the littoral plain and wadies of the Nabaq Protected Area) of South Sinai, Egypt was developed. Changes in dung density, estimated using distance sampling, are used as an index of changes in population size.

The two regions were divided into low and high density strata using the results of earlier surveys. Parallel transects were arranged in a regular pattern to ensure that maximum survey effort is allocated to the high density strata while keeping a representative cover of the low density ones. DISTANCE<sup>®</sup> 4.0 software was used to model the probability of detecting dung using half normal and hazard rate functions, and the Akaike information criterion to select between models. Habitat and terrain types were incorporated as covariates. The effects of biases caused by observer behaviour on the detection function were investigated. Five plots in the Qa'a plain were monitored for 15 months to estimate the annual decay rate of the dorcas gazelle dung using local regression.

The statistical power of the programme to detect population trends over time was assessed using time series provided by National Parks of Egypt starting in 1999 in addition to estimates resulting from the present work.

Spatial heterogeneity of dung density over the Qa'a plain was investigated using a Generalized Additive Model with gazelle dung density as the response variable and camel dung encounter rate, latitude, longitude and distance from the mountain edge as explanatory variables. The resulting model was used to predict spatial variation in gazelle dung density over the Qa'a plain using a Geographical Information System. The model fit was evaluated using graphical methods and Jack-knife resampling.

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## *Chapter 1*

# Introduction

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### **1.1 Conservation Legislation in Egypt: A Background**

Biodiversity, and natural resource conservation and management are becoming more and more important priorities of the environmental community in Egypt. In order to maintain the natural heritage of the nation, a dedicated law for natural reserves was issued by the Egyptian Parliament in 1983 and designated as Law 102/83. Law 102 has delegated the authority of declaring natural reserves to the Prime Minister following a proposal from the Egyptian Environmental Affairs Agency (EEAA). Eighteen protected areas have been declared so far, and the total number is expected to reach 22 by 2017. This will set aside about 15% of the total area of Egypt as natural reserves representing the habitat diversity, fauna and flora of Egypt.

As part of this scheme, St. Katherine Protectorate was established in 1986 by Prime Ministerial decree number 613/1988. This decree was later modified by decree number 940/1996 to include about 4350 km<sup>2</sup> of high altitude mountains.

### **1.2 General Ecology of St. Katherine Protectorate**

The St Katherine Protectorate contains a wide range of habitats and landscapes that are a consequence of varying climatic conditions, a wide range of altitudes, and variable topography. The landscape ranges from rugged mountains, which includes Mt. Katherine (2662 m), Egypt's highest peak, whose slopes are incised by wadi rivers. The wadi rivers generally slope towards the east, in the direction of the Gulf of Aqaba, or westwards towards the Gulf of Suez.

Because of these different conditions of temperature and humidity, there is a high level of biodiversity, particularly in the high altitude mountain area, which has the highest proportion of endemism in Egypt. Nineteen of the 317 species recorded for the area are endemic. There are 67 species of vertebrates, about half of which are reptiles, and 30 mammalian species. Because the region is at the junction of three continents, species from different biogeographical regions, such as the European wolf (*Canis lupus*) and ibex (*Capra ibex nubiana*), the striped hyena (*Hyena hyena*) and Tristram's grackle (*Onychognathus tristamii*) from Africa, and the Sinai rose finch (*Carpodachus synoicus*) from Asia, occur together. However, there are some unique

components to the fauna, with three species of endemic butterflies in south Sinai, including the world's smallest butterfly, the Sinai Blue Baton (*Pseudophilotes sinaicus*). In addition to a considerable proportion of Egypt's dorcas gazelle (*Gazella dorcas*).

The current study will focus on establishing a monitoring program that could be applied to keep track of the status of dorcas gazelle and start building time series for detecting and assessing trends in the natural reserves of South Sinai. The program is to be tailored in a way to suit the habitat and local requirements of the study region of an arid desert ecosystem. Also the logistics of available resources and manpower is a limiting factor to be considered in the methods to be utilized. Section 1.9 describes monitoring efforts applied to dorcas gazelle population of south Sinai prior to the current study in to which I contributed during the period of 1998 to 2000.

### **1.3 Aims of Present Work**

The aim of the work described in this thesis is to develop a comprehensive monitoring program that makes best use of the available resources and logistics within the St Katherine Protectorate and provides better quality data, in particular with a reduced variance in the estimates of relative abundance of gazelles. In addition, new avenues for obtaining information on the population ecology of *Gazella dorcas* are explored. The specific aims are to:

- Reduce the variance in the estimates of relative abundance through improved survey design, using habitat and terrain types as covariates in the analysis of survey data;
- Improve the power of the time series to detect changes in abundance with previous estimates for the period 1999 to 2000 in addition to results of the survey of the current study ;
- Investigate the rate at which dung decays;
- Incorporate spatial and ecological information into generalized additive models (GAM) in order to determine the relationship between gazelle distribution and habitat type;
- Formulate recommendations for management of the population and its range.

In sections 1.4 to 1.7 I will be listing general information about ecology, biology and conservation status of dorcas gazelle. Section 1.8 I will review methods of studying wildlife populations with special emphasis on those applied to ungulates and relation to current study.

### **1.4 Identification and Description of Dorcas Gazelle**

*Gazella dorcas* is the smallest member of the gazelle family. The height at the shoulders is 55-65 cm. and the body length ranges from 90-110 cm. The weight is about 15-20 kg. It is a small gazelle with no sharply contrasted pattern on the body. The general colour is pale sandy fawn, with a faint rufous-fawn band along the lower flank contrasting with the white belly. There is a rufous-fawn band on the blaze and a brownish-fawn stripe from eye to mouth, a white band, which runs from the base of the horn to the upper lip, separates these. There are long tufts of rufous-brown hairs on the knees of the forelegs, and a white patch on the rump. The forehead and bridge of the nose are generally light reddish-tan in colour. Old males may develop a fold of skin across the bridge of their noses. Both sexes have horns, which are of medium length, lyrate, strongly ringed, and curved backwards. The tips are bent upwards in a well marked curve. In males, the horns are 25-38 cm long; they bend sharply backwards and curve upward at the tips. Those of females are shorter (15-25 cm), straighter and less curved, with fewer ridges (Dorst and Dandelot, 1972; Kingdon, 1990).



Adult Female dorcas gazelle in Wadi Remthi , ST. Katherine -South Sinai  
captured by TrailMaster® camera trap.

## **1.5 Taxonomic Status of Gazelles in Sinai**

The dorcas gazelle of the Egyptian western desert belongs to the nominate subspecies *G. d. dorcas*, which is also reported to be found in the Libyan deserts further to the west. The dorcas gazelles of the Sinai Peninsula were reported to belong to the subspecies *G. d. saudiya* (Ellerman and Morrison-Scott, 1951; Harrison, 1968; Osborn and Helmy, 1980). However, Ferguson (1981) concluded that the dorcas gazelle of the Mediterranean maritime plains of Sinai belong to the subspecies *G. d. dorcas*, while those of the littoral of the southern Sinai belong to subspecies *G. d. Isabella*(=*littoralis*), with hybridisation occurring in western and eastern Sinai. He concluded that the Arabian gazelle *G. d. saudiya* does not occur in Sinai. *G. dorcas saudiya* was promoted to a distinct species as *G. saudiya* by Hammond et. al 2001 and was declared extinct.

## **1.6 Biology of *Gazella dorcas***

### **1.6.1 Life history and social structure**

Dorcas gazelles live to a maximum age of 17 years in captivity, and the maximum-recorded life span in the wild is 12-13 years. Dittrich (1968) observed that the first fertile mating in captive animals occurred when males were 19-20 months old. For females, first fertile mating occurred at 21-22 months of age (Dittrich, 1970; 1972). Gestation takes 169-174 days, and first parturition occurred in month 27 or 28 (Dittrich, 1968; 1972; Slaughter, 1971; Furley, 1986). Of the African gazelle species, only *G. cuvieri* has been observed to produce twins (Furley, 1986). However, Rode (1943) believed that twins do occur rarely in *G. dorcas*, and this is supported by the fact that twin ovulations were observed in the ovaries of six non-pregnant *G. dorcas* x *G. bennetti* hybrids (Furley, 1986).

For females, the first fertile mating occurred at 21-22 months of age (Dittrich, 1970; 1972). Gestation took 169-174 days, and first parturition occurred in the month 27 or 28 (Dittrich, 1968; 1972; Slaughter, 1971; Furley, 1986).

Ovulation in the genus *Gazella* does not appear to respond in changes in daylight length (Spinage, 1973). Reproduction can take place at any time of the year, although it usually coincides with the first flush of forage growth after a rainy season.

Peak numbers of young dorcas gazelle in Niger were observed in December (Grettenberger, 1987). Since neonates are usually hidden for several weeks before they begin to follow their mothers, this suggests that births peaked in November (Grettenberger, 1987). Newby (1978) observed births of dorcas gazelle all year round in Chad, but most births occurred during the cold season with the main peak occurring in September and a second peak in January. Loggers (1992) reports that most fawns born in Sidi Chiker gazelle reserve in Morocco were observed in October and March, and that births were recorded throughout the year in the Moroccan National Zoo. Fawns are visibly smaller than any age group and their horns cannot be consistently seen from a distance. Even when they are nearly 12 months old, their backs remain lower than those of adult females and their horns are about as long as their ears (Loggers, 1992). Fawns are weaned after about three months. Loggers (1992) reported that dorcas gazelle in Morocco live in groups of adult females and their fawns, juvenile females and juvenile males less than about 18 months old. Although female groups ranged over the territories of more than one male, they were most frequently found within the territory of a particular male. When accompanied by a territorial male, average group structure was recorded as 1.4 fawns (range 1-5) and 2.5 adult females (range 1-8). Lone adult females were also recorded. Males live either as lone territorial males or as bachelors. Bachelors were found singly or in herds of up to ten. The youngest members of the herds were about 18 months old, the age at which females begin to be harassed by territorial males (Loggers, 1992).

Adult males tend to defend territorial areas in which they keep groups of females. These territories are marked with dung middens, which are made by the male first pawing at the ground, then stretching over the scraped area to urinate, and finally crouching with his anus just above the ground to deposit his dung. Territorial males also advertise their presence by keeping at a distance from females and standing or lying alone for long periods. Females do not mark or display signs of territoriality (Wilson, 1991).

Dorcas gazelle seem to be able to tolerate high temperatures, which occur in their desert habitat for most times of the year. They are primarily active at dawn, dusk and throughout the night.

### 1.6.2 Habitat

Grasslands, shrub lands and semi-deserts are the main habitats used by dorcas gazelles throughout their range. They have been observed to prefer wadies dominated

by *Acacia sp.* during the dry season in upland habitat during the cold season ( Newby, 1978; Baharav, 1980).

### 1.6.3 Group size

Grettenberger (1987) found that the average group size of dorcas gazelle in the Niger plains was  $2.45 \pm 1.81$  (standard deviation). Group size varied from  $2.15 \pm 1.45$  in habitat with completely dry herbs and with little or no green foliage present, to  $2.39 \pm 1.34$  in habitat with drying green leaves on herbs and woody species, and to  $3.26 \pm 2.16$  in the most favourable habitat of herbs and woody species bearing leaves actively growing and with high moisture content. However, in the Negev desert, Baharav (1982) observed much larger groups of 5-22 adult females and young, plus territorial males, and bachelor groups of 2-5 males.

### 1.6.4 Foraging behaviour and diet

Dorcas gazelles are principally browsers but are also observed to take annual grasses and forbs when available (Baharav, 1980; 1982; Grettenberger, 1987). Field observations in Sudan showed that dorcas gazelles prefer *Acacia* leaves (Ghobrial, 1974). Valverde (1957) noticed that 50% of the rumen material of an adult female and 10% of an adult male in Western Sahara consisted of larval locusts (*Shistocerca sp.*). Faecal microhistological analysis showed that the diets of male and female occupying the same area are similar. Gazelles in North Africa increased their intake of shrubs and forbs over grasses during the dry season, even though these made up only 26% of the available vegetation (Loggers, 1991). Loggers (1991) suggested that this was because dicotyledonous plants contain higher levels of protein than grasses during the dry season. However, dorcas gazelle in Palestine were reported to show a marked shift towards grasses when rains caused a flush of new growth (Baharav, 1980; 1981). Grettenberger (1987) assessed the preference of dorcas gazelle for 405 available plant species in Aïa and Ténéré National Nature Reserve in Niger. The leaves of the tree *Mareua crassifolia* and the shrub *Leptadenia pyrotechnica* were the most highly preferred food, but the trees *Acacia tortilis* and *Balanites aegyptiaca* and the forb *Chrozophora brocchian* made up the bulk of their diet.

Ward and Slatz (1994) investigated the forage behaviour of dorcas gazelles in the Negev Desert, Israel. They found that their search paths deviated considerably from those that would be predicted by a random walk model. Paths were shorter than expected in areas of high plant densities. Bouts of concentrated feeding in small areas

were interspersed with long moves to new foraging areas, suggesting that these animals were repeatedly sampling their environment. In accordance with optimal foraging predictions (Stephens and Krebs, 1986; Roughgarden, 1991), gazelles selected plants with more and larger leaves than those randomly available, and concentrated their foraging activity in areas of highest forage density.

### 1.6.5 Thermoregulation and osmoregulation

Hygroscopic vegetation is believed to be a sufficient source of water for many desert animals if the animals restrict their feeding activities to the cool hours of the day (Taylor, 1968). Dorcas gazelles have several mechanisms to reduce their water loss when access to free water is unlikely. The total urine output volume is reduced by a factor of 3-4, and urine concentration is doubled (Ghobrial, 1974). In a study by Ghobrial (1974) conducted on captive gazelles, a 70% increase in urea and 52% in potassium concentrations in urine were observed under water deprivation, whereas a decrease of 43% in sodium and 26% in chloride urinary concentration occurred under the same conditions. Thermal load did not affect the concentration of solutes in the urine; rather it induced a reduction of 33% in urine volume and a 28% decrease in urinary chloride concentration. Dorcas gazelles normally form dry faecal pellets with low water content but, the water content of the pellets was reduced by about three-fold under water deprivation.

In spite of the fact that the dorcas gazelle is a true desert animal, its ability to endure the complete absence of water seems to be limited in very hot conditions. It can endure an absence of drinking water for about 9 days in winter, when ambient temperature is 20-30°C and relative humidity (RH) is 30-40%. An accompanying average weight loss of 13-19% was observed. During hot, dry conditions in summer and under ambient temperature of 35-45°C and RH of 10-30%, the gazelles could withstand only 3-4 days without free access to water. An accompanying weight loss of 12-20% was recorded (Ghobrial, 1974). Unlike other desert mammals, such as the camels, the dorcas gazelle cannot avoid evaporative cooling. Camels can withstand heterothermia of about 7 degrees (34-41°C) without sweating, stored heat is dissipated through the night and thus water is conserved. Even when gazelles are dehydrated, heat fluctuation can reach a maximum of only 2% (Ghobrial, 1974). Therefore, evaporation from these animals necessarily increases at high ambient temperature if the temperature gradient between the animal and the environment diminishes and radiation, convection and conduction becomes less efficient in keeping the animal

cool. Dorcas gazelle possess sweat glands, which they use for evaporative cooling (Ghobrial, 1970a; 1970b). Total water loss during the daylight hours in summer may be as high as 300-400 g dropping to 75-100g during the night (Ghobrial, 1974).

## **1.7 Conservation Status**

### **1.7.1 Global conservation status**

Dorcas gazelles occur in most of North Africa, from Mauritania and Morocco eastwards to Sinai in Egypt, and across the Suez Canal into Asia, as far south as Yemen and as far to the east as the western shores of the Arabian Sea. The species is considered to be extinct in Saudi Arabia (T. Wachter, pers. comm.). In Africa its distribution extends south as far as the mid-Sudan, Chad, Niger, and Mali (East, 1988; 1990) . According to East (1996) its occurrence in Nigeria is very doubtful, and it is considered extinct in Senegal. The species is categorised as “vulnerable A1a” in the IUCN 2000 Red List of Threatened Species( Taylor 2000). The Tunisian population is listed on CITES Appendix III. Figure 1 shows the range of dorcas gazelle in Africa.

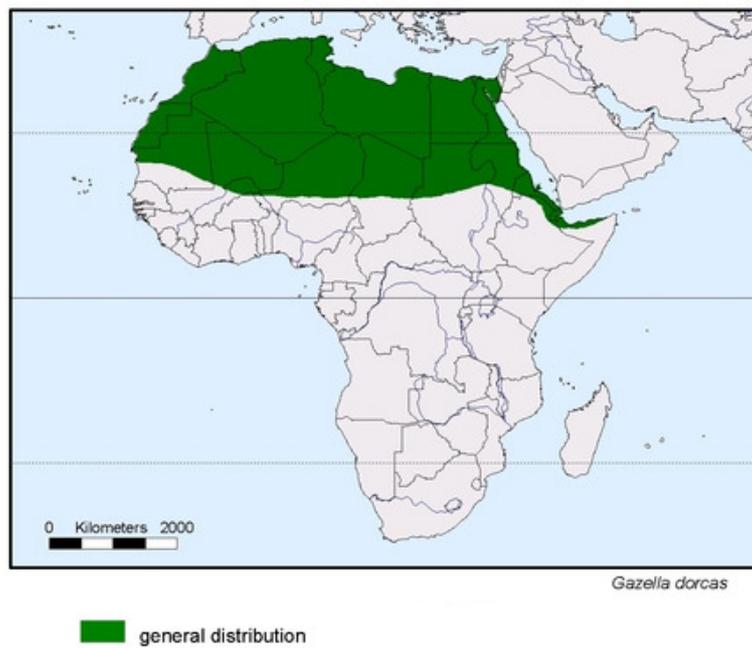


Fig (1.1) Range of dorcas gazelle in Africa

The presence of dorcas gazelle in a particular locality is dictated more by hunting pressure than the presence of suitable habitat. It is almost certainly the most common of the desert gazelles, but more detailed information on its fine-scale distribution is necessary for a realistic assessment of its conservation status.

### 1.7.2 Conservation status in Egypt

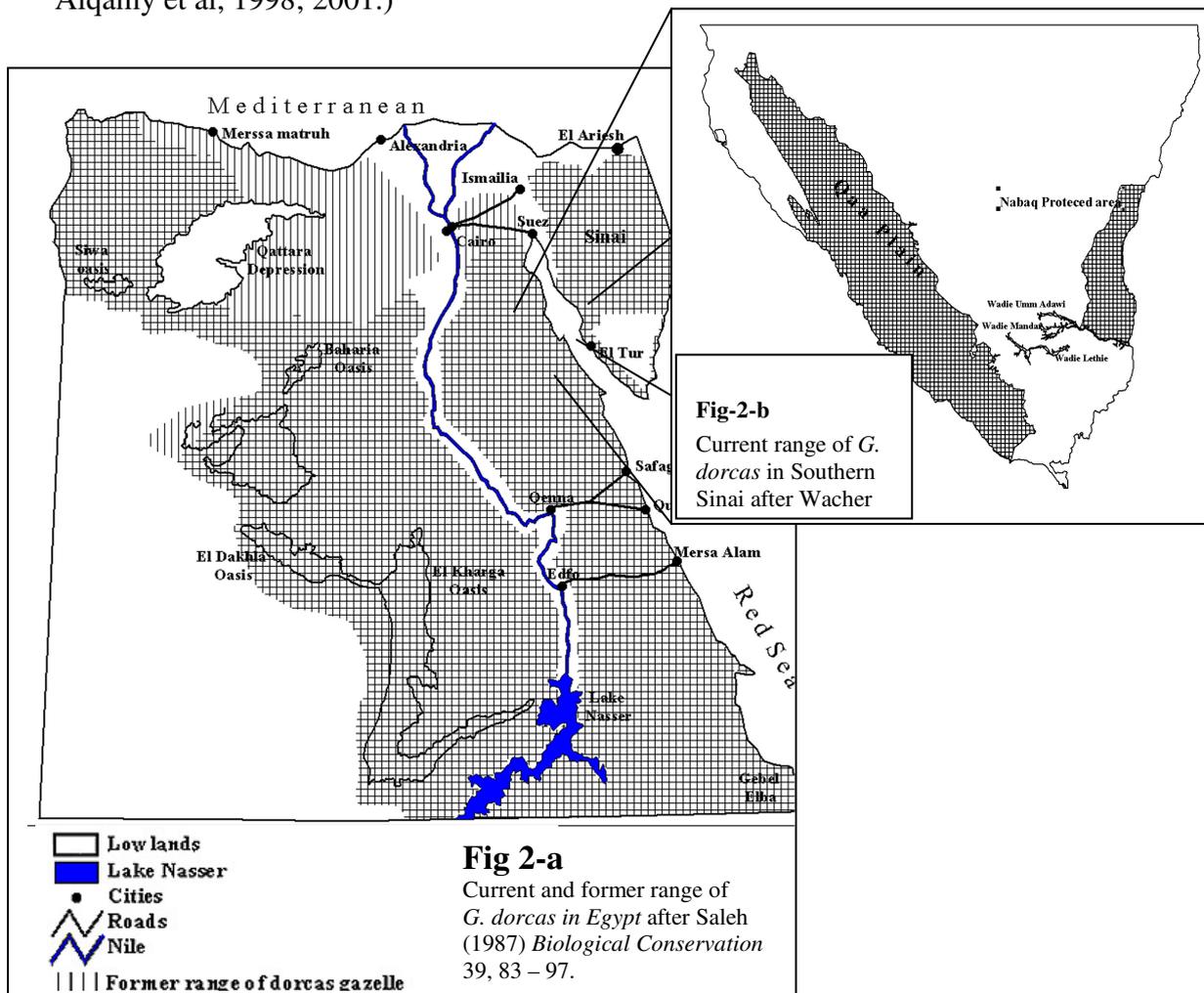
The dorcas gazelle was widely distributed in almost all of the Egyptian deserts (Osborn and Helmy, 1980), except for the southwest corner, bounded by 22°-28°N and 25°-28°E. Dorcas gazelle was not found in the mountainous areas of south Sinai, but occurred throughout the coastal plains of the Gulfs of Aqaba and Suez, and in the deserts of North Sinai (Osborn and Helmy, 1980). Its current range has obviously shrunk. Between 1981 and 1985, M.A. Saleh surveyed all but four of the areas where gazelles had been previously reported. He reports 61 former sites known to have gazelles all over the deserts of Egypt. In the Western Desert, there was evidence of the former presence of gazelles at 27 sites, but the species was considered to have disappeared from 12 sites in the western desert (Saleh, 1987). Of the 27 previously occupied sites in the western desert, only 4 were given the status *common* while 4 were designated as *rare*, and 3 as *very rare*. Four sites were not visited.

In the Eastern Desert, 12 of the 13 sites where gazelles were believed to occur were visited. The status of gazelles was classified as extinct at one site, *very rare* for 4 sites, *rare* for 2 sites, and *common* for 4 sites. Saleh (1987) also reported 12 new sites for gazelles in the Western Desert, at 8 sites gazelles were considered to be *common*. These records were provided by hunters and guides, and personal observations by Egyptian Wildlife Service personnel.

In Sinai, there was only 1 site where gazelles had been reported, but this was not visited by Saleh (1982). However, he lists 9 sites where new reports of gazelles had been obtained. At 5 of these gazelles were described as *common*, and at 4 they were described as *rare*. The results of Saleh's survey indicate that the range of *Gazella dorcas* in the Western Desert has undergone a considerable reduction in recent years. The species is no longer found in most of the Mediterranean coastal belt and areas west to the Nile delta to the Qattara Depression. Agricultural, industrial and urban expansion in the area southwest to Alexandria is presently encroaching on the most important areas of *G. d. dorcas* habitat in Egypt. However, remote areas of the Western Desert, such as Karawein, still hold relatively large populations of dorcas gazelles, with herds of more than 10 animals being reported (Saleh, 1987). The range of *Gazella dorcas* in the Eastern Desert has also been reduced in recent years. Gazelles have disappeared from areas north of the Cairo-Suez road, which have been undergoing extensive development and intensive military use for many years. South

of that road, and to the north of Qena-Safaga road, the species is still common and rarely hunted because of the rugged terrain and the presence of mine fields. Gazelles are also still common around wadies in the southern part of the Desert and along the Red Sea littoral, because there is very little human inference in that area. The largest population of *Gazella dorcas* in this region is found around Gebel Elba. Gazelles can still often be seen all over the northern plains of Gebel Elba. Gebel Elba was declared a national wildlife reserve, protected by the law by the P.M. decree No.450 on 1986.

In northern and central Sinai, gazelles appear to be rare and subjected to limited hunting pressure, mostly in wadi El Arish (Saleh, 1987). In southern Sinai the species is common in some localities, particularly the littoral Qa'a Plain. There are two main concentrations: a northern one, in the area between Wadi Abura and El Tur City; and a southern one, in and around Gebel El Mezraia. It is also found at lower densities on the narrow southern littoral of the Gulf of Aqaba, in the Nabaq Protected Area, and in the wadi systems of Umm Adawi, west Lethi and west Mandar (El Alqamy et al, 1998; 2001.)



## **1.8 Methods Used for Estimating Ungulate Abundance and Density**

No method of population assessment has yet been developed which allows the exact number of animals in an area to be determined. All methods for estimating abundance are subject to bias and uncertainty: the most valuable are those for which levels of uncertainty can be quantified and are relatively low. Further confidence arises, of course, if different techniques yield similar results.

Large mammals, especially many African species, often have a large range, which includes many different habitats and landscapes. Sutherland (1996) reviewed many of the methods used to survey mammals. Among these methods he reports that line transect, aerial line transects and dung counting as the most frequently used, while total counts and individual recognition are often applicable methods. Capture-recapture and use of feeding signs were classified as “sometimes applicable” methods.

### **1.8.1 Capture-recapture**

In this approach individuals are captured, marked in some distinctive way, and then released for subsequent recapture. The proportion of marked animals in the second sample can be used to estimate total population size if it can be assumed that the ratio of marked to unmarked animals is the same as the ratio of the number of animals originally marked to the total population. The principle has been called the Lincoln Index after F.C. Lincoln who developed the method for waterfowl studies (Lincoln, 1930)

There has been extensive development of theory and practice for capture–recapture methods in recent decades. (Otis, Burnham, White and Anderson, 1978, Brownie, Anderson Burnham and Robson, 1985). The Cormack-Jolly-Seber approach is probably the most commonly used family of capture-recapture designs. The analytical techniques associated with this design simultaneously and independently derived by Jolly (1965) , Seber (1965) and Cormack (1964). Estimable parameters from this basic design include apparent survival, abundance and births. The theory and analysis approaches of Cormack-Jolly-Seber models are thoroughly described by Burnham *et al.* (1987), Langtimm *et al.* (1998), Pollock *et al.* (1989) and Seber (1982). Bias is likely to be negative in estimates of population size in the face of heterogeneity in capture probabilities (Pollock, 1989). Pollock *et al.* (1989) presented

a detailed set of simulations which demonstrated the effect of population size, apparent survival rates and capture probability upon coefficient of variation for the parameters that can be estimated using the Cormack-Jolly-Seber approach.

Animal size is usually a limiting factor in most trapping studies: large traps require more manpower and are time consuming to use. Thus this approach is more often used for small mammals studies rather than larger ones. Although some principles of conventional sampling design apply to capture-recapture surveys, they are characterized by several unique features. Perhaps the most apparent deviation from traditional approaches to sampling is that animals are sampled multiple times. Animals may be marked with batch marks (group of animals receive the same marks) or marks that allow the animal to be individually identified. Capture-recapture studies should satisfy a number of primary assumptions. First, parameters estimated for the marked population must be applicable to the unmarked population of interest. That is, trapping techniques should target individuals of different sexes, ages or physiological conditions equally (Sulzbach, 1978; Vanderkist et al, 1999). Second, marking should not affect or change the behaviour or fate of the marked animals. Mark effects include mortality caused by improper attachment of a radio-transmitter (Garrott, 1985) or increased depredation of nests marked by the biologists (Rotella, 2000). Third, mark should not be lost; mark loss leads to a positive bias in estimates of abundance. Loss rates can be estimated by using double-marking techniques and the resulting estimate used to adjust for bias (Nicolas and Hines, 1993). Fourth, every marked animal alive in the population at a particular sample time must have the same probability of capture. Fifth, the fate of each marked animal should be independent of the fate of other marked animals. Sixth, resampling should be instantaneous. That is, birth, death, immigration, emigration must not occur during resampling process.

The assumptions associated with the closed model design are the same as those for general capture-recapture assumptions. In addition it include an assumption that during the entire period of sampling the population is both demographically and geographically closed, that's to say no individuals are allowed to be added to or subtracted from the population of interest (Otis *et al.*, 1978; Kendall, 1999). Practical issues involved in conducting a closed capture-recapture study are described by White and Anderson (1982). The report gives a detailed treatment of the subjects of laying

out sampling plots, the size of sampling plots and the frequency of sampling occasions. Sample size is a complex product of number of traps, the number of trapping occasions, the density of animals and density of traps. Detailed analytical solutions to the problems of sample size for studies that use the Lincoln Index approach are given by Robson and Reiger (1964). They also provide a first approximation of the sampling intensity and sample sizes necessary to achieve desired levels of precision.

### **1.8.2 Counting footprints and runways**

Looking for footprints in areas of soft ground, such as near water, is a useful way of detecting the presence of species. Counting the density of tracks gives a crude but quick indication of abundance. Counts of deer tracks per 16 km of dirt roads correlated reasonably with other estimates of density (Mooty and Karns, 1984). However, the results of this method may be affected by the fact that soft grounds are not randomly distributed and that they can hold tracks for variable periods of time. This effect may be somewhat moderated by clearing the ground after each count. Another problem is that it is difficult to know how many individuals produced the sets of prints that are observed. Biases in the estimates of density or relative abundance may be introduced by differences in behaviour between seasons and habitats (Sutherland, 1996).

### **1.8.3 Census counts made on the ground**

In this approach, an attempt is made to census all of the individuals in a particular area. In some cases, trained dogs are used to flush the objects of the survey from cover so that they can be counted. It is rarely used, because it is laborious and demanding in terms of manpower. In addition, the whole area must be surveyed sufficiently rapidly that the movement of individual animals cannot result in double counting or individuals being missed entirely.

### **1.8.4 Aerial surveys**

Some of the problems can be overcome by making the census counts from an aircraft. The use of aerial surveys in wildlife research is now routine. Census counts are usually confined to relatively small populations (perhaps <2-3000 individuals) of larger animals confined to a relatively small area that can be surveyed from the air within a few days. A series of parallel flight lines are laid out on a map of the area

under investigation so that the entire area believed to be used by the target species is covered. It is assumed that all animals within a specified distance of the flight line will be detected and counted and lines are spaced twice this distance apart. If the whole survey area cannot be covered in a single flight, it must be divided into a number of sub-areas, which are sufficiently far apart that animals are unlikely to move between them in the interval between successive flights.

Caughley (1980) describes a method of adjusting inner and outer streamers to define a 100m wide strip on the ground. Clearly, the spacing of the streamers depends on the height at which the survey is flown. This usually depends on terrain and type of habitat surveyed. In very open country, greater heights can be used (Sutherland, 1996).

The locations of all animals seen on the flights are usually marked on a map, as an additional check on double counting. Large aggregations may be photographed and the counts made from the prints to increase accuracy. An accurate count of a large group is impossible during the short time it is in sight. The camera must be positioned at the observer's normal line of sight. Watson (1969) discussed the combinations of lens, altitude, film and lighting that give the best results.

The fact that observers will be successful in counting every animal in the transect during aerial survey is doubtful. Observers may suffer "aerial survey hypnosis", characterised by an inability to focus, a tendency to daydream, and sporadic loss of memory such that the observer cannot recall whether or not he has recorded his last observation. Caughley (1980) describes how this problem can be overcome. Sutherland (1996) suggests it can be overcome by dividing the transect into segments of 2 minutes flying and recording, followed by an obligatory pause of 7 seconds during which no recordings are made. The area flown over in those 7 second sections is excluded from the transect and the number seen on the last segment can be jotted down during the dead time. This allows the observer to change focus of his eyes, straighten the kink in his neck, and to check that the other observers agree on the serial number of the segment.

Aerial survey counts may be biased because of missed or overlooked individuals. Many studies have reported such a phenomenon. Goddard (1967) reported that only 29% of black rhino (*Diceros bicornis*) known to be present in a plain, scattered-scrub

habitat were counted from the air, while Lamprey (1964) reported that 88% of African game in a plain, scattered-timber environment were likely to be counted. Edwards (1954) reported that 77% of moose (*Alces alces*) in snow and scattered timber habitat were counted. Caughley and Goddard (1972) showed from computer simulations and censuses of black rhinos that true totals could be estimated from the mean and variance of repeated censuses made at two levels of survey efficiency. Using this method, and comparing aerial counts with ground counts of deer in varying snow cover conditions, they concluded that 24% of the deer were counted during any one aerial survey and that ground counts tallied only about 58% of the deer in the area at the time (Caughley, 1980). However, this method operates on total counts and is not useful for estimating true density over an area that can only be sampled. An alternative method, proposed by Caughley (1974) involves estimating true density from the intercept of the regression of observed density per sampling unit on plane speed, height and transect width. Caughley (1976) used this method for estimating the sampled proportion of red kangaroos (*Macropus rufus*) in open country (Caughley, 1976).

Aerial surveys are usually carried out using high-wing aircraft with good downwards visibility. However, other platforms are also used. Noyes *et al.* (2000) compared the results of surveys of elk (*Cervus elphus*) population in Seld Springs Wildlife Management Unit, Oregon made using fixed-wing aircraft and helicopter. After correcting sightability bias, they concluded that population estimates from helicopter and fixed-wing surveys were not significantly different but noted that their test results had low statistical power.

### 1.8.5 Sample counts

The results from local censuses, carried out in parts of a species' range, can, in principle, be used as samples from which to estimate the total population size. However, because the distribution of large mammals is usually highly aggregated, such estimates are likely to have large variances.

An alternative approach is to count the number of animals (or some trace left by the animals, such as nests, spores, faeces) Seber, (1982) observed along a transect or transects through the species' range, and then scale up the resulting estimate of density to the entire study area (Anderson, 1970). In most situations, counts of

organisms in an area are incomplete and represent unknown proportions of the total population. Thus, correction for sampling observation probability (e.g., observability, sightability, visibility, and detectability) is needed. In particular, the probability of detecting an individual in a given survey area is required in order to estimate the population size or density (Wilson, 1996). There are many different kinds of transect, including strip or belt transects, and line transects.

Strip transect is a modified plot count where the plot is elongated rather than square, a modification made to enhance its coverage. It is assumed that all animals within a fixed distance of the transect are equally likely to be observed. However, it can be difficult to determine the appropriate width for such a strip and often the approximate distance of each animal from the transect line using a rangefinder or similar device. A mean sighting distance is then calculated and taken to be the actual width of the transect surveyed, with detections beyond being omitted. The strip transect approach, or some variant of it, is most frequently used when transects are surveyed from the air, because of the short time available to estimate the distance of each individual sighted from the transect line. The boundary of the strip to be defined by lengths of strings or coloured plastic strip attached to the wing struts of the aircraft. In flight, these stream out beside the cabin to form two parallel lines. The width of the strip varies with the position of the streamers on the strut and the height of the aircraft above the ground - the higher the aircraft the broader is the strip. The wing streamers therefore should be calibrated using trigonometry (Pennycuick and Western, 1972). In the past, the greatest source of error in aerial surveys resulted from variations in the height of the aircraft above the ground. However, the development of modern radar altimeters small enough to be accommodated in light aircraft has effectively solved the problem. The earliest known use of field methods based line transects was by J. E. Gross, who implemented bird surveys using this approach in Illinois in 1906 (Forbes, 1907; Forbes and Gross, 1921). Early analysis was based on the assumption that all objects were seen out to a predetermined distance. In this case, the method is again a modified quadrature sampling.

The concept of the strip count was refined a little by Kelker (1945), who recorded the distances of individual deer from the transect line and subsequently estimated a distance up to which it was reasonable to assume that all individuals were detected. The width of this strip was judged subjectively from a histogram of the data.

This approach was further enhanced by Hahn (1949) who the distance from the transect line beyond which it was assumed that objects are not detectable at a number of points along the transect. The width of the strip was estimated as the average of these distances.

The assumption of complete census inside a strip transect was relaxed by Anderson (1970), who termed this approach a belt transect. He defined a methodology where the perpendicular distances of objects (or animals) to the transect centre line are recorded and used to estimate density and population size. Anderson (1970) replaced the assumption of complete counts with three main assumptions. First, the design should be random or systematic with a random start point. Each transect is a sample unit, and the objects of interest are the variants associated with the transects. Second, transects should have a predetermined centre line and width to allow for accurate measurement of perpendicular distances. Third, only trained observers should do the fieldwork. Finally, the counted objects should be distributed randomly or in some well-defined contagious form.

The method assumes that the observer is more likely to miss far away objects than objects close to the transect line. This concept applies even if the observer searches in an irregular pattern around the centre line. Calculations are then made to account for the detected proportion of objects relative to the total population.

Distances from the transect line are grouped into convenient intervals or classes and a frequency distribution of the number of sightings in each class is constructed. The size of these intervals requires that the investigator apply his biological knowledge of the data and its meaning. A polygon formed by joining up the midpoints of these classes can then be used to estimate the mean strip width. The area below this polygon represents the number of items detected. The area above this polygon and below a line perpendicular to the Y intercept is an estimate of the number of items not detected (Anderson, 1970).

Two key papers laid the framework for estimation under perpendicular distance models. Gate, Marshall, and Olson (1968) developed a maximum likelihood estimate of abundance; they assumed a negative exponential model to account for the

deterioration in detectability with increased distance from the observer. This provided a basic framework, which could be used with other, more plausible models, for the detection function (Seber, 1973).

Burnham and Anderson (1976) provided the framework for the analysis of line transect data that is currently in use today. One of the key results in their formulation specifies how the fitted detection probability function  $f(l)$ , where  $l$  is the perpendicular distance of an object from the track line, could be used in estimating density from distance data.  $\hat{D} = \frac{n \cdot \hat{f}(0)}{2L}$  where  $\hat{f}(0)$  is the fitted on detection function evaluated at zero distance,  $n$  is the number of detections, and  $L$  is the total length of all line transects. The theoretical framework of these parametric models was provided by Ramsey (1979).

The monograph by Burnham, Anderson, and Laake (1980) was a milestone in the development of line transect methods. It provides a coherent and through framework for design and analysis. The monograph used Fourier series model for estimation, and provided a software package (TRANSECT) that allowed biologists to take advantage of the new analysis methods. Buckland (1985) developed the Hermite polynomial model and compared its performance in modelling the detection probability function with the Fourier series, exponential quadratic (Burnham et al., 1980), exponential power series (Quinn, 1977; Pollock, 1978), and hazard-rate (Hayes and Buckland, 1983) models. On the basis of that comparison, the exponential models were found not to be competitive. A unified adjustment formulation was developed by Buckland (1992) and Buckland *et al.* (1993a) that incorporated the preceding models as well as additional ones. The software package DISTANCE<sup>®</sup> (<http://www.ruwpa.st-and.ac.uk/distance/>), a much enhanced version of TRANSECT II, provides wildlife biologists with a simple way to carry out the complex statistical computations necessary to implement the distance sampling approach.

Chen (1996) suggested another method to estimate the detection probability function using a kernel estimate of  $f(0)$ , which he showed could provide an asymptotically unbiased and robust estimate of density. The kernel estimate of the probability density function can be viewed as a smoothed version of a histogram. Instead of counting the

number of data values falling into bins, each data point is weighted by a smooth function centred at the data point. Chen (1996) has shown that the kernel method is a useful technique in analysing data from line transect sampling that does not need to assume a parametric form for the detection function. Therefore, it is very much data-oriented modelling approach and is robust against a changing detection function during a line transect survey.

Chen (1996) also compared the performance of the kernel estimate with Fourier series estimate. Comparison showed that the estimate of  $f(x)$  by the kernel method does not require an explicit truncation width in calculation. Simulation studies also showed that the kernel-based confidence intervals had better coverage than their Fourier counterpart. As Buckland (1992) pointed out, the kernel method has the disadvantage of not being applicable to data subjected to severe rounding error. This usually occurs when perpendicular sighting distance is derived from the sighting angle, which is frequently rounded to the nearest  $5^\circ$  or  $10^\circ$ .

In recent years, a large amount of work has been done to refine the quality of the estimates coming out of the method and to develop its use for monitoring population trends (Marques *et al.*, 2001; Plumbtree, 2000; Headley, 2000; RUWPA, 2001). DISTANCE, Version 4.0 incorporates Multivariate Covariate Distance Sampling described as MCDS (Marques, 2001; Marques and Buckland, in prep.; Marques *et al.*, in prep). The MCDS uses a key function and series expansion formulation to model the detection function that incorporates covariates other than distance into the detection function. Although conventional models are robust to pooling, they may still be biased if covariates that affect detectability are correlated with object density. For example, if detectability and density both vary by habitat, this will cause some bias in the overall density estimate. To mitigate this problem, we can estimate a detection function for each stratum (habitat, in the above case). However, we often find that there are some strata with too few data to reliably estimate the detection function. In this case, if detectability is correlated with animal density, then our estimates of stratum abundance will be biased. Incorporating additional covariates makes it possible, in theory, to model variation in the detection function across strata when there are few data in some strata.

The covariates are assumed to affect the scale parameter of the key function, which controls the "width" of the detection function. Of the four key functions available in conventional distance sampling analysis, the half-normal and hazard-rate are both available in the MCDS analysis. The other two either do not have a scale parameter (uniform model), or provide an implausible shape close to zero distance (exponential model).

### 1.8.6 Indirect surveys (pellet groups count)

In many occasions during ecological investigation animals under investigation are either in low numbers or so elusive or secretive in habits that they cannot be detected. A situation like such could remarkably affect the ability to detect them is resulting in few or very few detections. Modelling detection function requires relatively large number of detections and consequently few detections render modelling the detectability problematic or even impossible.

A compromise over such situations is to survey more conspicuous objects that their density and abundance are of direct relation to those of the animal population under investigation. Such an approach is termed indirect survey, with the resulting estimates are rather termed as indices of population density and abundance. Following, an investigation is usually conducted to work out the relation between indices and population estimates resulting in consequently converting the former into the latter.

Indirect survey is a well-established method to estimate population throughout the literature. The method could be tracked back to 1954 where Kozicky *et. al.* used the analysed signs counts of woodcock on the ground to estimate the population. Also Taylor and Williams (1956) used pellet groups counts to estimate the population density of wild rabbit *Oryctolagus cuniculus*. Following many workers used pellet group counts to get population indices and estimates for many animal taxa. Earlier examples of these could be found in Lowe (1956) for mourning doves; Emlen *et al.* (1957) for mice; Neff (1958) for big game; Rogers *et. al.* (1958) for deer; and Adams (1959) for snow-shoe hares. Moreover, other signs of presence have been in use for getting indices of animal abundance and densities. Nests and vocalization are very widely used in primates surveys (Whitesides *et. al.* 1988, Plumptre 2000, Van

Krunkelsven 2001, and Russon *et. al.* 2001). Dung piles of faecal pellet group counts are of considerable use in estimating density and abundance of ungulates. Prominent examples are the African elephants *Lexodonta africana* (Fay & Agnagna 1991, Jachmann 1991, Barnes & Alerts and Plumtre & Hariss 1995 ), Sika deer *Cervus nippon* (Marques *et. al.* 2001) feral pigs (Hone & Martin, 1998) duiker *Cephalopus sp.* (Koester & Hart 1988) bushbuck *Tragelaphus scriptus* , Cape buffalo *Syncerus Caffer* (Plumtre & Hariss 1995) and dorcas gazelle *Gazella dorcas*( Lawes & Nanni 1993 and El Alqamy *et. al.* 2001) .

Indirect methods of counting faecal pellets of ungulates may have some shortages compared to direct counts in only giving an estimate of the overall abundance with no information about age classes or age structure of the population. Faecal pellets surveys have the advantage of yielding estimates of average abundance over a wide time span of several months whereas direct counts produces estimates of abundance and density for the day on which count was made, which may inherently contain misleading information on habitat use.

Dung counts or pellet surveys could be done using several methods. Those are clearance plots, standing crop or along line transects. Clearance plot provides more accurate estimates of absolute abundance than the standing crop one but it is much laborious and requires a relatively larger number of plots (Marquez *et.al.*2001).

Indirect surveys utilizing dung counts are usually associated with defecation rate and dung decay rate estimation. These two parameters are essential for getting real animal abundance estimates out of the indirect estimates. Generally the relation between direct animal abundance ( $N$ ) and dung abundance ( $N_{dung}$ ), decay rate ( $r$ ), and Defecation rate ( $D$ ) is expressed as  $N = \frac{N_{dung} \times r}{D}$ . However, since all members of right side of the equation are estimates then each have it own variance which adds some imprecision to the final estimate.

Defecation rates are optimally estimated from direct observation of wild animals. Daily defecation rates vary in between seasons and depend on diet as well. Generally it is impractical to observe wild animal in natural conditions. Defecation

rates obtained from captive animals introduces bias to abundance estimates. In practice, it is better to estimate defecation rate from semi captive animals in natural habitat kept on minimum supplementary feed.

Several methods are reported in the literature for dung decay rate estimation (Barnes & Barnes 1992, Plumptre & Hariss 1995, Nchanji & Plumptre 2001, and Marques *et. al.* 2001). Some methods involves monitoring fresh dung on timely basis with a prior definition of a stage at which faecal pellets are considered to be decayed even if still apparent somehow. Another involves locating fresh dung on timely basis for a period close to the maximum duration of the most durable pellets then recording the number of pellets remaining till the time of the survey and modelling this proportion parametrically as function of time.

Jachmann (1991) evaluated four methods for estimating elephant density in Nazing Game Ranch, Borkina Faso, against the results of an aerial survey total count. Dropping counts over line transects managed to yield values of elephant population size closer to the value obtained in aerial total counts than any other technique used.

From the above discussion and listing of methods used to assess ungulate populations a decision was made to utilize indirect survey of gazelle faecal pellets using distance sampling as the sampling protocol. This decision is justified by the following: 1) Dung is usually affected by many factors most obviously, temperature, rain fall, dung beetles and trampling by own species or others. Provided the conditions of the study region under investigation it is known to be an arid region with very low number of animal dwellers, 2) pellet group survey seems to be a good candidate methodology for getting abundance and density estimates. 3) However, low animal numbers would impose considerable limitations on the possibility of estimating the defecation rate in natural or semi natural conditions. 4)Also, due to the limited resources of manpower and logistics available to the disposal of population monitoring a combination of distance sampling along line transects targeting dung pellets would be tempting approach to investigate. 5)Line transect would allow coverage of large areas with relatively modest logistics and it will be a good trade off of not compromising the precession of estimates provided the robustness of the models targeted for data analysis.

## **1.9 Monitoring efforts in St. Katherine Protectorate up to 2000**

Although the St Katherine Protectorate was established in 1986, no management plan or monitoring activities were established due to a shortage of resources. In 1996 the Egyptian government, in collaboration with the European Union, started a project aimed at establishing a sound, well-managed protectorate in St. Katherine. One aim was to recruit and train qualified staff to carry out a monitoring and observation programme that would provide a basis for sound management decisions. As part of that general scheme a monitoring program was required for the large mammals in the protectorate. Dorcas gazelle was one of the major species that was considered as one of the remaining large mammals still occurring in the vicinity of Saint Katherine Protectorate.

The habitat used by dorcas gazelle is mostly open plain habitat, so aerial survey was the most obvious technique to use for monitoring this population. However, trial surveys indicated that sightings rates from aerial surveys would be too low to provide reliable estimates of abundance. Ground-based line transects were also tested during the early stages of the project, but again sighting rates were low. In the first presence/absence survey conducted by Wachter (1996) only one group of four animals was sighted in the Nabaq protected area in four visits.

In the view of these results the current study chooses to investigate the possibility of using indirect measures of dorcas gazelle presence, such as the dung piles deposited by male dorcas gazelles. As noted above, males around their territories deposit these piles, which are relatively easily detected. Here below I list all the previous efforts done in monitoring dorcas gazelle in south Sinai. Those efforts served as the first approaches applied leading to the finalisation of the program in the form applied in the current study.

### **1.9.1 Phase I: Local knowledge**

The first approach was to identify the main areas where gazelles still occur, and to provide a preliminary classification of their conservation status. The most obvious method was to interview local people in order to obtain information about the areas where gazelles used to occur, and where they still occur. Interviews were conducted as part of a process to recruitment local community guards, not as

dedicated questionnaire for wildlife assessment. When interviewees reported that gazelles had disappeared from a particular area, they were asked why they thought this had happened. This helped in defining a preliminary list of threats to the population. They were also asked if any other gazelle species (such as the mountain gazelle, *Gazella gazella*) occurred in the Protectorate.

The local people all agreed that only dorcas gazelles occurred in the area, and that there had been a noticeable decline in the population over the preceding 10 years. They believed that the most probable reasons for the decline were long periods of drought and over-hunting. Some interviewees also mentioned the presence of feral dogs (Wacher, 1996).

### 1.9.2 Phase II: Presence-absence surveys

The first dedicated survey of dorcas gazelles in St. Katherine Protectorate was conducted in 1996. The survey design was developed by Dr. T. J. Wacher (Zoological Society of London) and involved a rapid assessment of a large area. It therefore required a simple technique for determining the presence/absence of the species in a short time with reasonable reliability. The method needed to be equally applicable to mountain slopes, wadies, and gravel or stony plains. The survey was undertaken by driving through selected areas recording location using GPS, and human activity (scored as housing, camps, wells, farms or quarries). Stops were made at more or less regular intervals to walk fixed distances over the ground. All signs of gazelle presence (tracks, and faecal piles) along these 'transects' were scored on a standard tabulation. Additional data recorded including date, duration of transect and habitat type. In most locations, 'transect' width and line were not strictly controlled but observations were collected by three people walking 300-500 m on a front 20-30 m wide;

Ground survey sites were not selected at random. On the contrary, they were selected to maximise probability of detecting gazelle presence. The line of march was modified to pass by any trees or bushes if they were characteristic of the area. Dorcas gazelles rest and feed near such sites and signs are most often encountered in close association with low bushy *Acacia sp.* trees. It was considered pointless to miss such opportunities and return misleadingly negative results as a result of a strict protocol. The locations of all signs were plotted on a map to identify areas where aggregations of gazelles occurred. The survey covered the south and north Qa'a plain, Nabaq

Protected Area, the Lethie wadi system and some parts of the plain basins in the north of the St. Katherine Protectorate (Wacher, 1996)

Wacher (1996) concluded that the gazelle population in these areas was threatened by three main dangers: habitat loss due to the continuing development and urbanisation in the region of Sharm El Sheikh city; population fragmentation, because the population in Nabaq and Lethi was effectively isolated from that on the Qa'a plain by the spread of Sharm El Shiekh and human disturbance associated with this; and over hunting together with the presence of feral dogs, whose numbers had increased rapidly over the preceding 6-8 years. Although, no direct attempts were made to assess the presence of feral dogs in South Sinai in 1996, evidence from camera traps ([www.trailmaster.com](http://www.trailmaster.com)) set-up in St. Katherine Protectorate in March 1999 indicated that feral dogs occur at several locations in the Protectorate.

### **1.9.3 Phase III: Activity index**

Further stages of the program development involved improving the quality of the data collected in the surveys. Surveys were conducted along 1 km transects, and quantitative estimates of activity, rather than the simple presence or absence of traces, were recorded. Tracks of gazelles that had crossed the transect were counted. The average number of tracks per km of survey effort in a particular study region was used as an index of gazelle activity (El Alqamy, 1998). The value of the activity index for each transect was associated with the coordinates of the mid-point of the transect and Kriging was used to interpolate the sampled transects to the survey area.

Kriging is a prediction method designed for geophysical variables with a continuous distribution. Kriging interpolates a property value for each output raster cell by calculating a weighted average of the property under investigation at nearby vectors, points or nodes. Closer points/nodes are weighted more heavily than more distant ones in the calculation. The Kriging method analyses the statistical variation in values over different distances and in different directions to determine the shape and size of the point selection area as well as the set of weighting factors that will produce the minimum error in property value estimate. The spatial distribution of continuous property is estimated from sample points where the values of this property are measured or known. The degree of spatial continuity based on these known values can be expressed as a variogram. The Kriging method uses information from the

variogram to determine the optimal set of weights (Cressie and Noel, 1991; Swan and Sandilands, 1995).

Kriging was used to generate contours of equal gazelle activity in order to document its distribution in the area under investigation. A pilot survey was done in 1998 involving South Qa'a plain and Nabaq area. The study area was about 1145 km<sup>2</sup> in Qa'a Plain and 156 km<sup>2</sup> in Nabaq area. During this pilot survey, 13 transects (mean length 500m, range 460- 1050m) were surveyed in Qa'a plain and 9 transects (mean length 900m, range 250-2050m) in Nabaq area. The total survey effort was 7.0 km of transects in Qa'a Plain and 7.95 km in Nabaq. There were only 3 detections of gazelle dung in Nabaq and about 21 in Qa'a Plain. On the other hand, 71 fresh gazelle tracks were detected in Nabaq while only 48 were detected in Qa'a Plain. The survey yielded an estimate of 8.93 track/km in Nabaq and 6.89 track/km in Qa'a. Although the number of transects and their coverage of the area was limited, the maps were useful for identifying where concentrations of activity had been encountered. Only tracks that were relatively fresh (3-4 days old) were recorded and so the activity index was also used to determine if gazelles were present continually in a particular area, or if they were only transient. However, this methodology was only appropriate when the terrain was mostly gravel or sand, because tracks were less likely to be recorded on a rocky substrate.

#### **1.9.4 Phase IV: Distance sampling**

In the most recent phase of the programme, survey techniques that would make best use of the currently available resources and logistics and, yet, provide relatively reliable estimates and information about the target population was developed. The results of surveys in 1999 and 2000 for using distance sampling were reported in El Alqamy *et. al.* (2001). The selected methodology had to cause minimal disturbance to the animals, and so direct counts and capture-release methods were out of the question. Aerial surveys were attempted in March 1999, but very few animals were observed and it was difficult to adapt the technique to the mountainous terrain in the Protectorate. It was recognized that this aerial survey trial was not feasible with only big military helicopters that were available, due to the unfamiliarity of the aircraft crew with the objectives of the survey. The craft was also not equipped with sufficient headsets, which resulted in a lack of systematic recording. Only 22 mammals were observed, none of them gazelles. A total of 7.7 flying hours were used to cover the whole south Sinai area flying about 970 km of linear distance (Wacher,

1999). The fact that no flying permissions could be granted for non-military aircraft due to security reasons stopped any further pursuit of the aerial survey technique development.

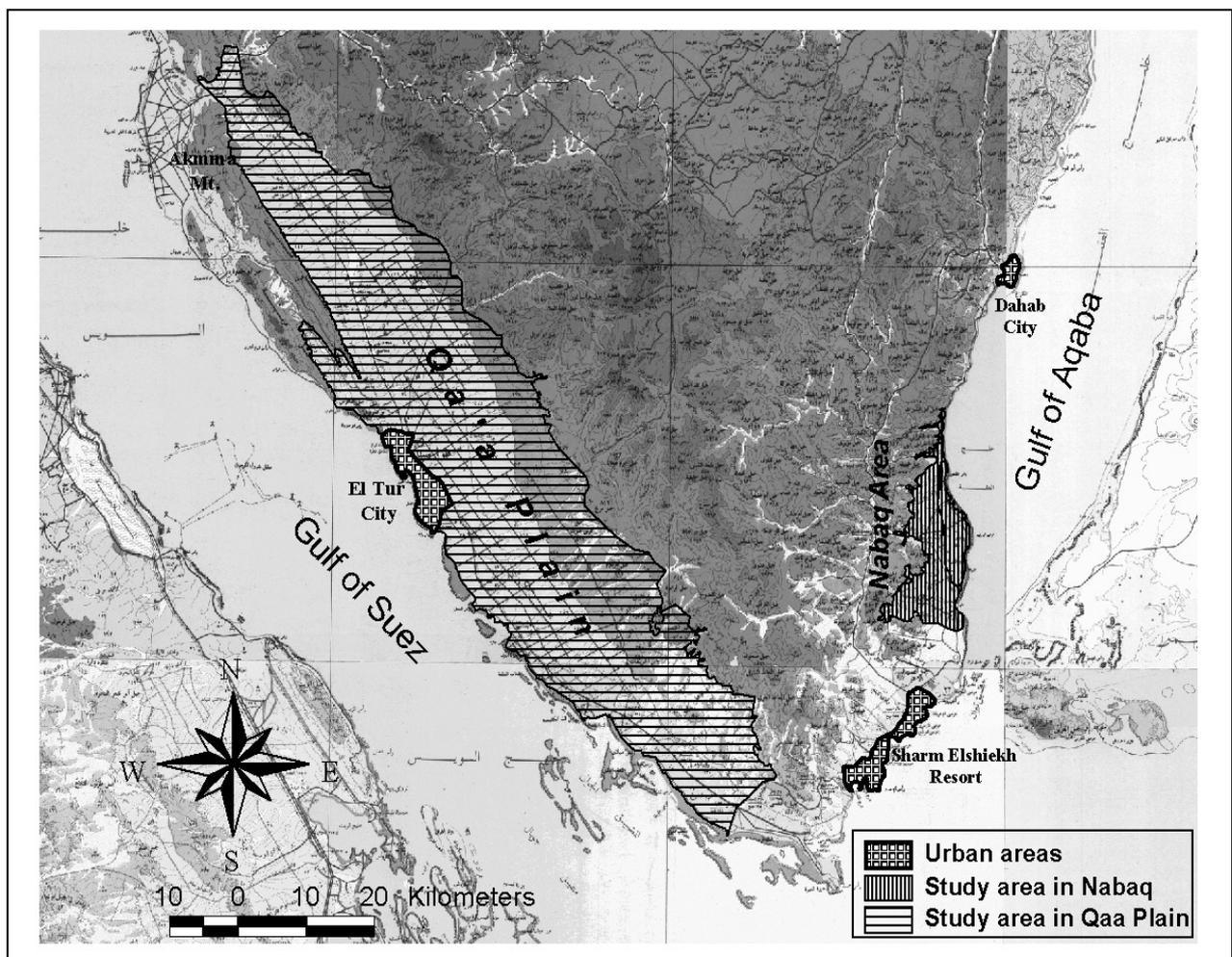
The survey teams gained extensive experience of identifying gazelle traces in different habitats and terrains during previous presence-absence surveys, and it was decided to use this site knowledge in the new monitoring programme. The final decision involved the choice of an appropriate measure of gazelle abundance and a survey design. Two pilot surveys using distance sampling of gazelle dung were undertaken at the end of 1999. These indicated that distance-sampling techniques could be used effectively in the Protectorate. In the light of these pilot surveys, a standardised survey design was devised, and surveys have been conducted annually for all key areas since the beginning of 1999.

## Chapter 2

## General Methodology

**2.1 Study area**

Previous investigations (Saleh, Wachter 1996, 1999 and El Alqamy, 1998) had shown that dorcas gazelle are still occurring on the eastern and western littoral plains of the Gulf of Suez and the Gulf of Aqaba. The Qa'a Plain is situated on the Gulf of Suez side of the Sinai Peninsula; the relatively narrow southern coastal littoral of Gulf of Aqaba is referred to as the Nabaq area. (Figure 2.1).



**Fig. 2.1** Map of study area showing location of Qa'a Plain and Nabaq area. .

**2.1.1 Qa'a Plain**

The Qa'a Plain is a largely gravel region that extends along the western side of the Sinai peninsula from Ras Mohammed ( $27^{\circ} 42' 00''$  N) in the south to the Mt. Akmma,

about 55 km north, and then to El Tur City (28°42' 00"N). It is about 125 km in length, and the width varies from 5.0 km in the north up to 23 km at its widest area near to El Tur City. The total area is about 2232 km<sup>2</sup>. The southern boundary of the study area was defined as the border of the Ras Mohamed National Park, and the eastern boundary was edge of the mountain line. The plain slopes southwest towards the coast. The highest altitude is about 700 m above mean sea level. The plain is interrupted by many dry wadie rivers that run from the northeast to the southwest and carry seasonal water into the Gulf of Suez. The vegetation is usually scant and patchy, except along the path of the seasonal water flows. Patches of *Acacia* trees are found either as belts along the mountain edge or as islands in the inner wadi rivers. Shrubs include *Licium sahwi*, *Crotalaria aegyptiaca*, *Ochradenus buccatus*, *Haloxylon persicum* and *Retama reatem*. *Zygophyllum coccineum* is abundant through out the plain. The area is classified as semi-arid desert, receiving less than 100 mm of annual precipitation. The rainy season extends from May to October and from January to March.

The terrain is mostly gravel plain but several other types are occasionally occurring. Salt marshes are not uncommon along the coastal line. Boulder fields are abundant in the northern part of the plain especially around the 3-5 kilometers adjacent to the edge of the mountains.

### 2.1.2 Nabaq area

The Nabaq area contains unique habitat types. The terrain is a mixture of salt marshes, gravely-to-sandy plains, and medium-sized sand dunes built around vegetation. It is bounded to the west by igneous mountains. These mountains are incised by narrow wadi rivers that harbour a range of plant communities. The 170 km<sup>2</sup> study area was designated as the area extending from the Sharm El Shiekh Airport northward to the end of the coastal plain. The salt marshes extend for about 15 km along the coastline, with a maximum width of about 1 km. The littoral plain consists mainly of the delta fan of wadi Kid. In the middle of this fan the terrain is mostly boulder field, interrupted by small ditches formed by seasonal water flows. Stone deserts occur in the north-west corner of the study area.

The vegetation in the Nabaq area is very different from that of the Qa'a Plain. It can be divided into two main communities: the coastal plain community; and the inner wadies community. The coastal plain community is made up of four species of sand

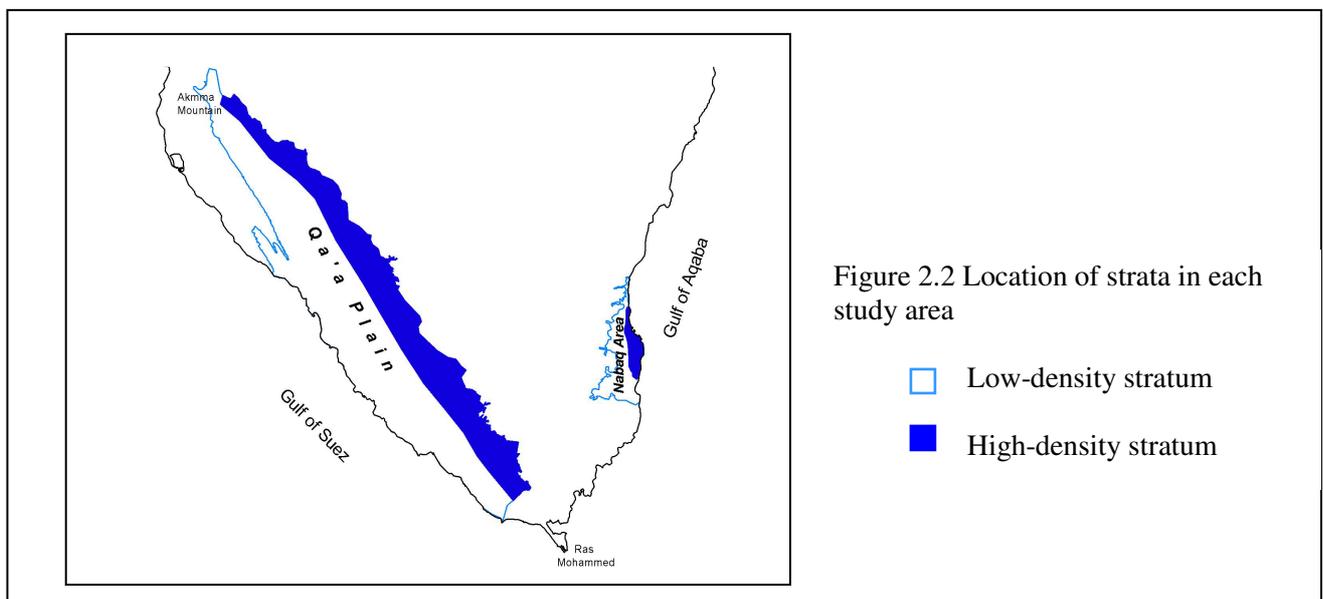
dune building vegetation: *Zygophyllum album*, *Limonium axillare*, *Nitraria retusa* and *Salvadora persica*. The latter two are the dominant species. In addition, the mangrove *Avicennia marina* is present along the coast (Al Mufti 2000). *Limonium axillare* is confined to a zone within 1 km of the coastline.

The vegetation community of the inner wadies has some similarities to that of Qa'a plain: *Acacia* trees are abundant and many of the same shrub species are found here. However, a dwarf shrub species, *Cleome drosifolia* which is dome-shaped shrub is unique to this area.

## 2.2 Methodology

### 2.2.1 Stratification Scheme:

The study area in the Qa'a Plain and Nabaq were divided into high-density and low-density strata on the basis of the densities of gazelles observed in previous surveys (Alqamy, 2001). The high-density stratum on the Qa'a Plain was a narrow strip adjacent to the mountains edge. Findings from previous studies were applied to stratify the study region. Previous surveys of Qa'a plain (Wacher 1996 and Alqamy, 2001) showed that heavy gazelle presence in Qa'a plain is confined to areas not far to the west of the mountains edge. The extent of this is varying along the plain. Gazelles may spread up to 10 km away to the west of the mountains in the southern parts of the plain while they are confined to 3 km only to the west of the mountainous edge in the north of the plain. This information were used to shape the extents of the high-density stratum in Qa'a plain. The high-density stratum in Qa'a Plain is of total area of about 787 km<sup>2</sup> and the low-density stratum is about 1444 km<sup>2</sup>. In Nabaq, the high-density stratum was defined as the coastal area of *Salvadora* and *Netraria* dunes that are thought to be preferred by gazelles as food plants. The rest of the coastal plain and the inner wadies were designated as the low-density stratum. The high-density stratum of Nabaq comprises about 40 km<sup>2</sup> and the low-density stratum is about 130 km<sup>2</sup>. Figure 2.2 shows the location of the strata in the Qa'a plain and Nabaq area.



### 2.2.2 Survey Design

Previous surveys (Wacher 1996 and Alqamy, 2001) provided important insight about how gazelles are distributed in south Sinai. It could be summarized in the following points. Two core concentrations were noted in the southern eastern corner of Qa'a plain and a smaller one in Nabaq protected area. There is a considerable clustering and variation in the distribution of dorcas gazelle throughout the study area. Also there was a noticeable gradient of gazelle density with high values in the east of Qa'a plain and grading down to the west. Thus, there was a need for a representative coverage for the whole area with appropriate effort allocation to the highly populated areas relative to the low density ones. Also the direction of the transects was assigned perpendicularly to the density gradient. Systematic segmented sampling was used to identify the sample transects. It involves randomly superimposing a systematic set of segmented parallel lines onto the survey region. The lines were assigned different arrangements according to the sampled stratum. Since very few detections were expected in the low-density stratum, relatively more effort was allocated to the high-density stratum. The location of all survey transects is shown in Figure 2.3.

#### 2.2.2.1 Qa'a high-density stratum

A random start point was picked, from which a series of 2-km transect segments along parallel lines were surveyed. Transect segments were spaced by 3 km interval and the parallel lines were placed with spacing distance of 5 km.

#### 2.2.2.2 Qa'a low-density stratum

In this stratum each 1-km long transects, spaced 5 km apart, were surveyed.

#### 2.2.2.3 Nabaq high-density stratum

A random start point was picked, from which a series of 2-km long transects, spaced 2 km apart, were surveyed. Since the high density stratum in Nabaq was much smaller in area compared to Qa'a plain, the spacing between transect lines was less to allow for allocating more sampling effort

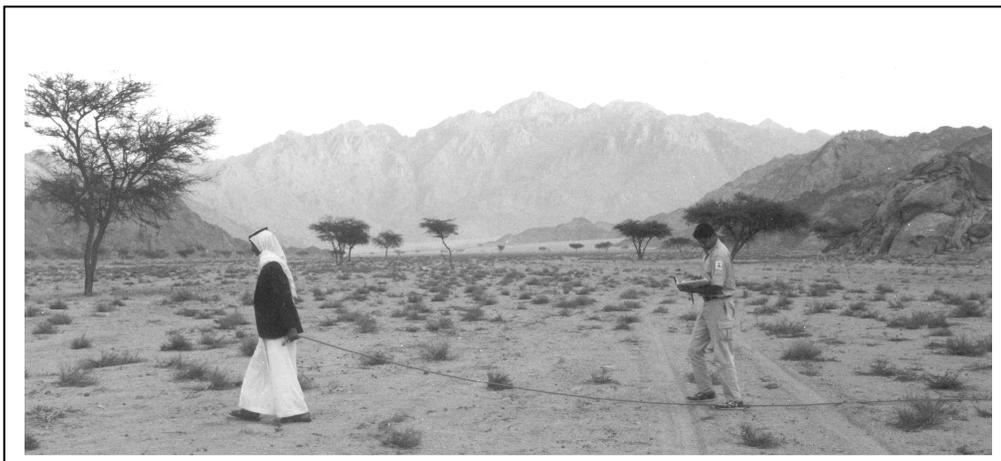
#### 2.2.2.4 Nabaq low-density stratum

In the low-density stratum 1-km long transects were spaced 3 km apart.

### **2.3 Sampling**

#### **2.3.1 Survey methodology**

A Garmin 12 GPS receiver was used to locate the start point of each transect. The exact location of the start and end point was recorded to the nearest 1 m. Transects were surveyed by a two-person team, an observer and a recorder. The observer walked ahead of the recorder, pulling a 20 m rope that acted as the reference point for the track line (Fig. 2.3). Transects were made at a constant bearing of 45° in Qa'a Plain, and on a 0° bearing (straight to north) in the Nabaq area. These bearings were chosen to run perpendicular to the water-made ditches, which gazelles prefer to walk along. At the beginning of each transect habitat and terrain type were ranked according to category system summarized in table (2.1). Ranks were afterwards used as covarites for modelling detectability. The occurrence and location of all recently deposited gazelle and camel dung piles within 10 m of the transect were recorded. The age of dung piles was estimated and assigned to one of six categories. Only relatively recent dung piles in categories 1, 2 and 3 were recorded as perpendicular distances to the rope. Older dung ranked as 4,5 and 6 was overlooked. The perpendicular distances greater than 1.0 m were measured with an ultrasonic distance measurer (RadioShack), shorter distances were measured with a metal tape, and all were recorded to the nearest 1.0 mm. Gazelle tracks crossing the transect line from side to side of the rope were recorded as tally marks.



**Fig. 2.3** Field method of distance sampling along line transect, the observer is dragging a 20 m rope that acted as the reference line.

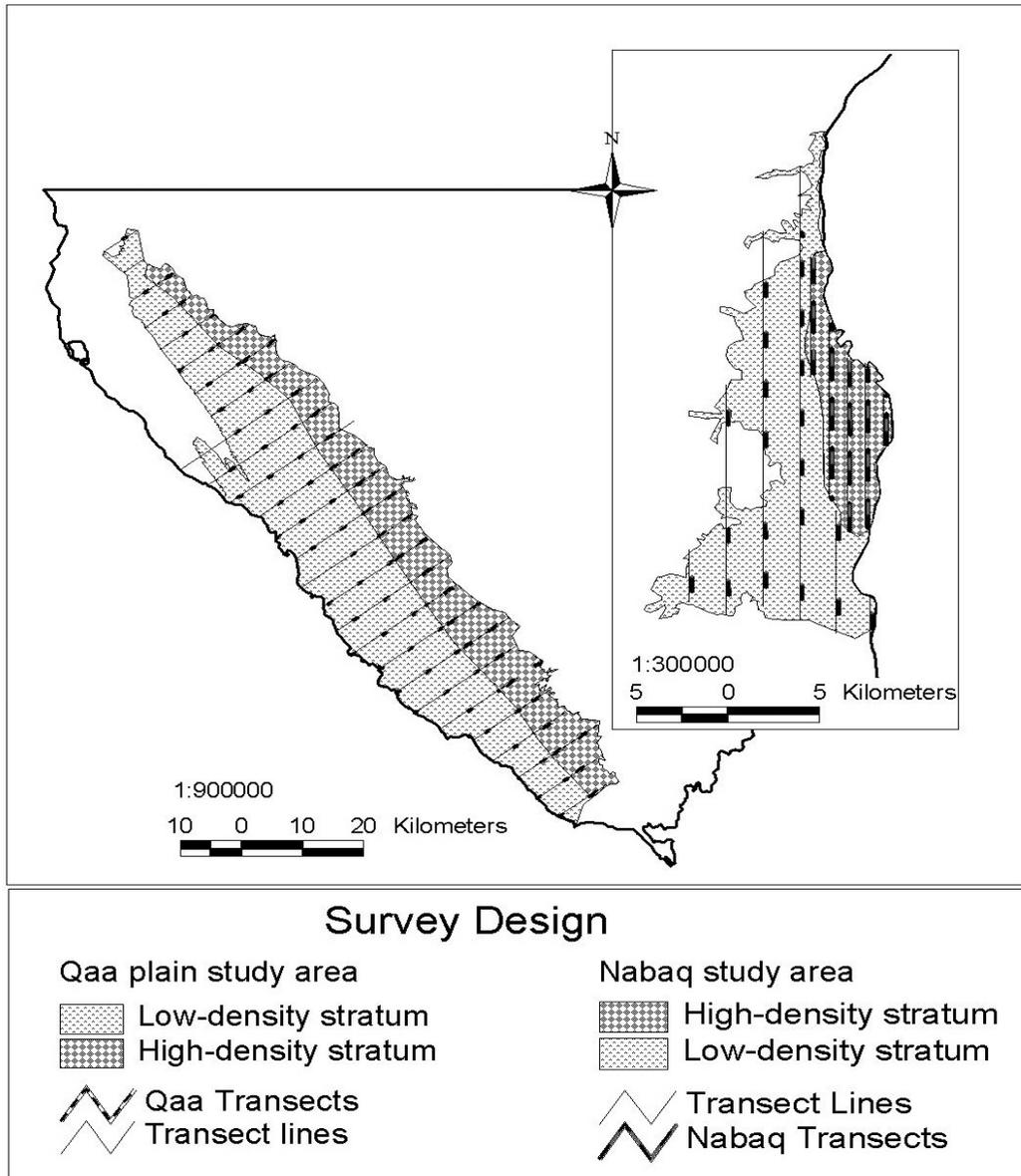
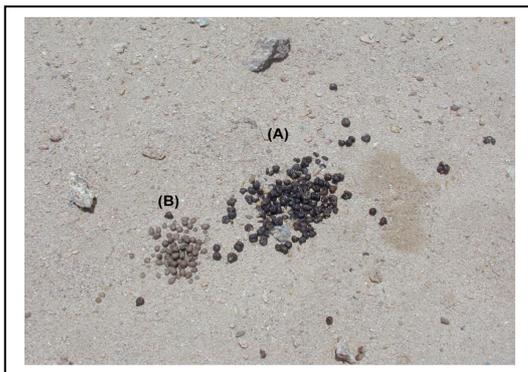


Figure 2.3  
Location of survey transects in Qa'a Plain and Nabaq area

### 2.3.2 Gazelle dung age categories

Gazelle dung was classified into six categories on the basis of its estimated age. Typical examples of each type are shown in Fig. 2.4.:

- 1- **Fresh** dung, characterised by its wet, shiny appearance, often accompanied by urine.
- 2- **Less than 1-week old dung**, which was dark in colour and discrete in shape, with some sand sticking to the pellets.
- 3- **More than 1 Week but less than 1 Month old dung**, which was dry and lacked a dark appearance
- 4- **Old dung**, which was light brown in colour, with longitudinal cracks
- 5- **Very old dung**, which was dry , scattered or mashed.
- 6- **White dung**, Bedouin claim it is at least one year old if not older so it is considered as the oldest droppings available.



**Fig. 2.4** Illustrations of different dung categories.

- A. Fresh dung  
B. <1 week old dung



- 1 week to 1 month-old dung (category 2)



d) Old dung 1 < month to 1 year months old (category 3)



e) Very old dung 1 < Year (category 4)



F. (category 5 & 6) Scattered mushed or White dung

### 2.3.3 Habitat and terrain categories

Habitat and terrain type was recorded for each transect, based on the prevailing conditions within 200 m of the transect start point. The categories used are shown in table 2.1

table (2.1) Terrain and habitat categories used in this study.

| Category | Terrain             | Category | Habitat                      |
|----------|---------------------|----------|------------------------------|
| 1        | Coastal Marsh       | 1        | <i>Acacia</i> belt           |
| 2        | Sand dunes          | 2        | <i>Salvadora</i> dunes       |
| 3        | Gravel Plain        | 3        | <i>Nitraria</i> dunes        |
| 4        | Wadie               | 4        | <i>Zygophyllum</i> shrubs    |
| 5        | Boulder field       | 5        | Bare ground                  |
| 6        | Sandy plain         | 6        | Scattered Vegetation         |
| 7        | Hilly ground        | 7        | Dwarf shrubs & <i>Acacia</i> |
| 8        | Coastal stony plain | 8        | Dense shrubs                 |

### 2.3.4 Dung decay rate

In parts of the Qa'a Plain where gazelles or their presence indications were observed most frequently, five plots were selected to estimate the decay rate of gazelle. Selection was made taking in consideration to have different habitat and terrain types represented. The dimension of each plot varied, according to the degree of droppings spread, from 10x10m to 20x20m. The number of droppings at initial installation was counted for each plot, and each dropping was marked with a long nail, and its location relative to landmarks, such as pieces of vegetation or boulders within the plot, was sketched. Each plot was visited once per month. During this monthly visit the detectable marked (with a nail) dung piles are counted and the remaining amount is recorded. Each monthly visit would take about 15 minutes within the site.

### 2.4. Data Analysis

The density of dung in the two study areas was estimated using the computer package DISTANCE 4.0, beta 3 (<http://www.ruwpa.st-and.ac.uk/distance/>). The beta version of this software was used to take advantage of new features, which allowed covariates to be used in the modelling of detection probabilities. Conventional distance sampling (CDS) analysis assumes that the detectability of objects of interest is only affected by the perpendicular distance to the transect line. However, in real time situations there are possibly other factors that affects the detection function such as vegetation cover and others like inter-observer variability. Including the effect of these co-factors is added to the new version of DISTANCE where a Multi Covariate Distance Sampling (MCDS) is allowed. For the current study, many types of terrain are traversed through the study region each of which has its own texture, colour and particle size. Also types and densities of vegetation available through the study region are highly variable ranging from bare ground to dense mangrove bushes. These are inevitably introducing sources of variability into the detectability of gazelle

droppings. The habitat and terrain categories associated with each transect segment were used as covariates. For each observation  $x_i$  a vector of covariates  $z_i$  ( $z_{1i}, z_{2i}, \dots$ ) was recorded. This vector  $z_i$  was then used to calculate  $f(x, z)$  i.e. the detection function of  $x_i$  at given covariate  $z_i$

Thus the detection function becomes:

$$f(x | z) = \frac{g(x, z)}{\int g(x, z) dx}$$

The methods are described in more detail in Marques (2001), Marques and Buckland (in prep.) and Marques et al. (in prep.)

**Modeling the effect of covariates**

Like the Conventional Distance Sampling (CDS) engine, the Multi Covariate Distance Sampling (MCDS) engine uses a key function + series expansion formulation to model the detection function. The difference is the incorporation of covariates in addition to distance into the key function. So,

$$g(x, z) = \text{key}(x, z) [1 + \text{series}(x)]$$

where  $g(x, z)$  is the probability of detecting an object at distance  $x$  and covariates  $z$ ,  $\text{key}(x, z)$  is the key function, and  $\text{series}(x)$  is the series expansion.

The covariates are assumed to affect the scale parameter of the key function,  $\sigma$ . The scale parameter controls the "width" of the detection function. Of the four key functions available in the CDS engine, the half-normal and hazard-rate are both available in the MCDS engine; the other two either do not have a scale parameter (uniform), or provide an implausible shape close to 0 distance (exponential).

Half-normal key function,  $\exp\{-x^2/2\sigma(z)^2\}$

Hazard-rate key function,  $1 - \exp\{-[x/\sigma(z)]^{-b}\}$

The scale parameter is modeled as an exponential function of the covariates:

$$\sigma(z) = \exp(\beta_0 + \beta_1 z_1 + \beta_2 z_2 + \dots + \beta_q z_q)$$

where  $q$  is the number of covariate parameters. The term inside the brackets is akin to a linear model – the  $\beta$ 's are parameters to be estimated, with  $\beta_0$  corresponding to the intercept. The exponential term prevents the scale parameter from being negative.

Use only key functions that incorporate a scale parameter  $\sigma$  (e.g. half-normal or hazard-rate, but not the uniform).

Let :  $\sigma(z_i) = \exp\left(\beta_0 + \sum_j \beta_j z_{ji}\right)$

Then  $f(x_i | z_i) = \frac{k\{x_i, \sigma(z_i)\} \left[1 + \sum_{j \neq k} a_j p_j(x_{is})\right]}{\mu(z_i)}$  where  $\mu(z_i) = \int_0^w g(x, z_i) dx$  is the effective half width

and thus abundance of gazelle dung is estimated by the formula :  $\hat{N} = A \cdot \frac{\sum_{i=1}^n \hat{f}(0 | z_i)}{2L}$

where  $s_i$  indicates the size of the detected cluster (which equals 1 in the case of objects which do not occur in clusters), and  $p_i$  is the probability that object  $i$  is detected, given  $z_i$  and that it is in the surveyed area of size  $2wL$ .

### 2.4.1 Detection function model fitting

To fit of the half normal and hazard rate models to the observed variation in dung locations with distance from the transect line was assessed. Different combinations of these models with the three adjustment terms available in the program (cosine, simple-polynomial and hermite-polynomial) were used. Adjustment terms were selected sequentially with using likelihood ratio test and significance level of 0.15.

Half normal :  $\exp(-y^2 / 2\sigma^2)$       Cosine :  $\sum_{j=2}^m a_j \cos\left(\frac{j\pi y}{w}\right)$

Hazard Rate :  $1 - \exp(-y / \sigma^{-b})$       Simple polynomial =  $\sum_{j=2}^m a_j \left(\frac{y}{w}\right)^2$

Hermite polynomial =  $\sum_{j=2}^m a_j H_{2j}(y_s)$       where :  $y_s = \frac{y}{\sigma}$

$y$ = perp. distance,  $w$ =transect width.

The selection of terms was based on the likelihood ratio test. The test statistic used is

$$\chi^2 = 2(\ln \lambda_1 - \ln \lambda_2)$$

where  $\lambda_1$  and  $\lambda_2$  are the maximum values of the likelihood functions associated with two rival models. New terms are only added if they result in a significant change in the likelihood.. The process continues until adding new terms does not improve the likelihood or the maximum number of terms is reached. The conventional significance level is 15% ( $\alpha=0.15$ ), so that terms are only added if  $\chi^2 \geq 2.07$

### 2.4.2 Density estimation

The same detection function was used for the high- and low-density strata in the Qa'a Plain, because very few detections were made in the low-density stratum. In addition, insufficient droppings were found in either of the Nabaq strata to estimate the detection functions. Data from 2001 were therefore pooled with datasets collected in the same area in 1999 and 2000. Data were stratified by year, but no data on habitat and terrain categories were available from the 1999 and 2000 surveys so these could not be used as covariates.

Once an appropriate detection function had been identified, density was calculated for each area and stratum using the general formula:

$$\hat{D} = \frac{n \cdot \hat{f}(0|z)}{2L}$$

where:

$n$  = number of detections

$L$  = total survey effort in length units

Density estimates was obtained per stratum. Global density estimate is the mean of strata estimates weighted by stratum area.

### 2.4.3 Relating Dung Density & Abundance to Direct Density

Generally dung abundance is related to the actual abundance of animals if the amount of daily faeces added by individual animal (defecation rate) and the period of time, (usually in days) that faecal pellets remain on the ground in a detectable state (dung decay) rate are known. Barnes Jansen (1987) used the relation  $N = \frac{N_{dung} \times r}{D}$  to estimate density of elephants from estimates of faecal pellets density where  $Y$  is density of faecal pellets and  $r$  is the decay rate and  $D$  is the defecation rate. Jachmann (1988) used the same approach with elephants but with different equation designed

for the dry season where defecation rate is estimated for dry season and surveys are

conducted only in dry season  $N = \sum_{a=1}^{100} \frac{729 D_a}{\sum_{i=1}^T (1 - iL_s) R_s}$  where  $N$ = number of elephants,

$D_a$ = number of droppings in quadrat  $a$ ,  $T$ = period of dropping accumulation ( $n$  days),  $L_s$ =fraction of droppings disappearing per day in hot season and  $R_s$ =season-specific defecation rate (dropping/elephant/day). Jachmann (1984) also used the formula

$N = \frac{D \ln 2}{R t_{1/2}}$  where  $D$ = number of faecal droppings,  $R$ =Dry season defecation rate and

$t_{1/2}$  = the defecation rate (days) at which half of the original droppings are unrecognizable. Thus it is generally using the two parameters of defecation rate and droppings decay rate as multipliers to the indirect abundance estimates to reach to the direct estimate of the population size. The defecation rate is always the nominator while the decay rate is the denominator with any other parameters added correspondingly to each case according to methods used in estimating those values or habitat conditions.

The same approach is possible in DISTANCE 4.0 software where indirect abundance and density estimates obtained through line transect (or point counts) are converted to direct estimates. Indirect surveys such as nest counts and dung counts are handled using multipliers, two multipliers are added: one for the object production rate and another for the mean time to object disappearance. This is the approach that will be adopted in this study since analysis is heavily conducted using DISTANCE analysis engine. However, direct estimates won't be reported in this study since defecation rate is not available now and yet to be determined in an independent investigation in later date.

#### 2.4.4 Activity Index and Encounter Rate

The average number of gazelle tracks per km of transect was used as a measure of gazelle activity, called the Activity Index, in each area. The number of gazelle and camel dung piles encountered per km along each transect was called the Encounter Rate, and was used to investigate the relative distribution of these two species using a Cremer von Misese- type test (Syrjala, 1996).

### 2.4.5 Modelling spatial variation

In order to obtain some insight into the factors which may affect the distribution of gazelles on the Qa'a Plain, a Generalised Additive Model (GAM) was developed relating the gazelle dung density as response value to four factors namely are: distance between the transect mid-point and the mountain edge, camel dung Encounter Rate, latitude, and longitude. Regression spline smoothing (Wood, 2000 and 2001) was used to summarize the trend of the response variable as a function of the predictors. Generalized cross validation was used for smoothing parameter selection. The resulting model was then used to predict gazelle dung density over the Qa'a Plain on a 2.5 km x 2.5 km grid. Spatial variation of dung density was modelled only for Qa'a plain. There were insufficient data from the Nabaq area to apply this approach. Jackknife bootstrapping was used to check the fitted model.

## Chapter 3

## Results

In this chapter I report the results for all the investigation done using the methods described earlier in the previous sections.

### **3.1-Detection function**

The detectability of dung and the observed sample size differed substantially between the two study areas and so the detection functions for the two study areas under consideration are presented separately.

#### **3.1.1-Detection function of Qaa plain.**

Perpendicular distances were grouped in intervals corresponding to the detection function intervals shown in Table (3.1)

Table 3.1 Intervals used to fit detection function for Qa'a plain.

| Cell | Cut Points |       | Observed value | Expected value | $\chi^2$ value |
|------|------------|-------|----------------|----------------|----------------|
| 1    | 0.00       | 0.491 | 24.0           | 21.37          | 0.324          |
| 2    | 0.491      | 0.982 | 21.0           | 20.42          | 0.016          |
| 3    | 0.982      | 1.47  | 15.0           | 18.68          | 0.725          |
| 4    | 1.47       | 1.96  | 14.0           | 16.40          | 0.351          |
| 5    | 1.96       | 2.46  | 11.0           | 13.88          | 0.599          |
| 6    | 2.46       | 2.95  | 18.0           | 11.42          | 3.787          |
| 7    | 2.95       | 3.44  | 12.0           | 9.24           | 0.828          |
| 8    | 3.44       | 3.93  | 7.0            | 7.44           | 0.026          |
| 9    | 3.93       | 4.42  | 4.0            | 6.04           | 0.691          |
| 10   | 4.42       | 4.91  | 8.0            | 5.00           | 1.798          |
| 11   | 4.91       | 5.40  | 2.0            | 4.21           | 1.164          |
| 12   | 5.40       | 5.89  | 2.0            | 3.59           | 0.702          |
| 13   | 5.89       | 6.38  | 1.0            | 3.04           | 1.370          |
| 14   | 6.38       | 6.88  | 2.0            | 2.53           | 0.113          |
| 15   | 6.88       | 7.37  | 5.0            | 2.05           | 4.227          |
| 16   | 7.37       | 7.86  | 0.0            | 1.61           | 1.605          |
| 17   | 7.86       | 8.35  | 1.0            | 1.20           | 0.035          |
| 18   | 8.35       | 8.84  | 2.0            | 0.86           | 1.492          |

Total chi-square value = 19.8514 Degrees of Freedom = 15  
Probability of a greater chi-square value, P = 0.17771

Inspection of Table 3.1 and the detection function plot revealed that the detection function is not particularly a good fit to the data, as indicated by the relatively large  $\chi^2$  value. The fitted detection function (Fig 3.1) shows a rapid

decline in detection probability between 1.0 and 2.0 m, relatively adjacent to the observers. Thus an alternative form for the detection function was investigated.

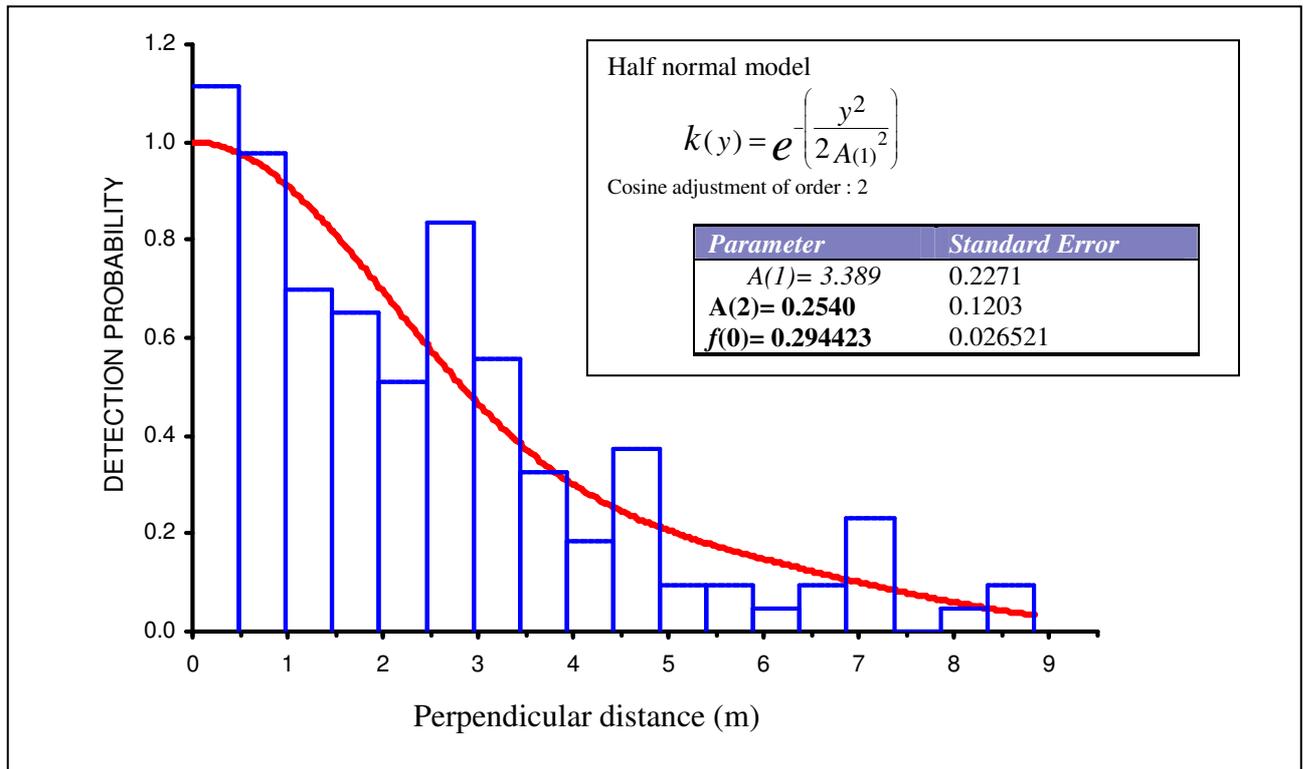


Fig. 3.1 Preliminary global detection function for gazelle dung in the Qaa plain

The same interval cut points and the half normal function were used, but observations were truncated at 6.5m. A more satisfactory fit was obtained with a substantially reduced chi-square value (Table 3.2), and the detection function shown in Fig. 3.2. was accepted

**Effects of Covariates :**

The effect of covariates was tested using the half-normal and hazard-rate functions with various combinations of adjustment terms. All combinations were made with habitat and terrain rankings as covariates. Table 3.3 shows the results of this analysis.

Table 3.2 Interval cut points modified to truncated data

| Cell | Cut Points |       | Observed value | Expected value | $\chi^2$ value |
|------|------------|-------|----------------|----------------|----------------|
| 1    | 0.00       | 0.491 | 23.0           | 19.58          | 0.598          |
| 2    | 0.491      | 0.982 | 20.0           | 19.03          | 0.050          |
| 3    | 0.982      | 1.47  | 16.0           | 18.01          | 0.224          |
| 4    | 1.47       | 1.96  | 13.0           | 16.12          | 0.604          |
| 5    | 1.96       | 2.46  | 9.0            | 14.58          | 2.133          |
| 6    | 2.46       | 2.95  | 17.0           | 12.25          | 1.845          |
| 7    | 2.95       | 3.44  | 13.0           | 10.42          | 0.639          |
| 8    | 3.44       | 3.93  | 8.0            | 8.24           | 0.007          |
| 9    | 3.93       | 4.42  | 5.0            | 6.59           | 0.385          |
| 10   | 4.42       | 4.91  | 5.0            | 4.90           | 0.002          |
| 11   | 4.91       | 5.40  | 6.0            | 3.69           | 1.442          |
| 12   | 5.40       | 5.89  | 1.0            | 2.58           | 0.970          |
| 13   | 5.89       | 6.38  | 2.0            | 1.83           | 0.016          |
| 14   | 6.38       | 6.88  | 1.0            | 1.18           | 0.028          |

Total Chi-square value = 8.9434 Degrees of Freedom = 12  
 Probability of a greater chi-square value, P = 0.70776

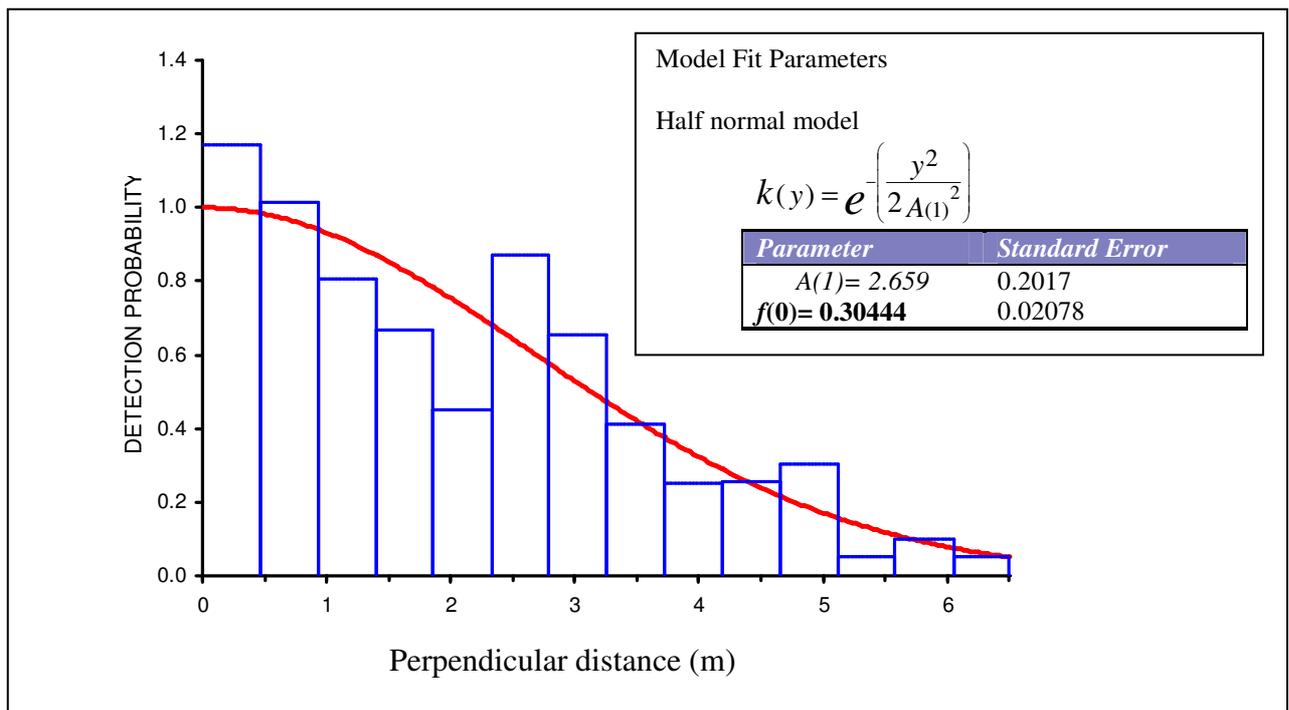


Fig. 3.2 Global detection function fitted to truncated gazelle dung data from Qaa plain.

Table 3.3 Fits of various detection functions to data for Qaa plain.

| Key function | Adjustment term    | No. of parameters | AIC value |
|--------------|--------------------|-------------------|-----------|
| Half-normal  | Cosine             | 4                 | 458.65    |
| Half-normal  | Simple polynomial  | 3                 | 459.89    |
| Half-normal  | Hermite polynomial | 3                 | 459.89    |
| Hazard rate  | Cosine             | 5                 | 467.18    |
| Hazard rate  | Simple polynomial  | 4                 | 467.62    |
| Hazard rate  | Hermite polynomial | 4                 | 467.62    |

The half-normal family generally provided a better fit to the data with consistently lower AIC scores. Within each family, models with the cosine adjustment term had the lowest AIC values. On basis of minimum AIC the half-normal model with cosine adjustment was selected, fits with this model are shown in Fig. 3.3. Model Fit parameters and points estimates are listed in table (3.4)

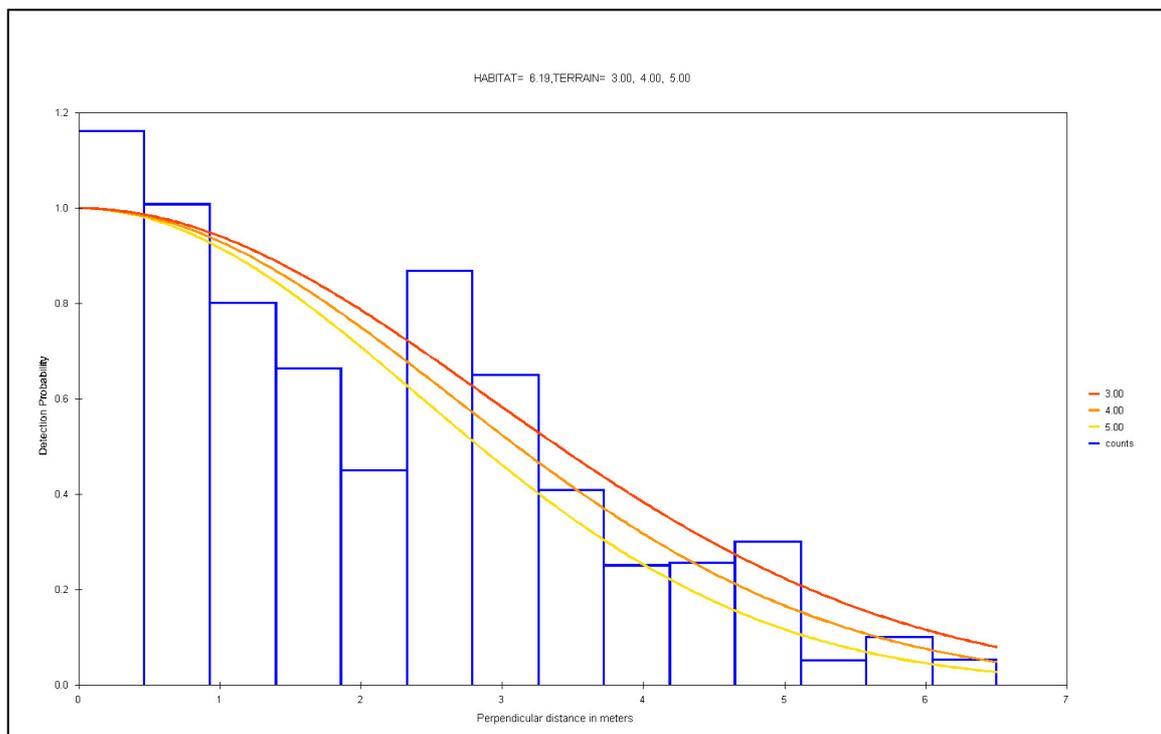


Fig. 3.3 Fitted detection functions for data from Qa'a plain using terrain and habitat ranks as covariates

**Model Parameters:**

The half-normal model with cosine adjustment has the following form

$$k(y) = e^{-\left(\frac{y^2}{2\sigma^2}\right)} \quad \sigma = e^{(A(1)+f_{cn}(A(2))+f_{cn}(A(3)))}$$

Table (3.4) Model Fit parameters and point estimates for Qa'a plain detection function

| Parameter     | Standard Error | Description                                   |
|---------------|----------------|---|
| A(1)=2.004    | 0.07552        | Intercept of the scale parameter $\sigma$     |
| A(2)= -0.1087 | 0.0948         | Coefficient of covariate HABITAT.             |
| A(3)= -0.0903 | 0.0846         | Coefficient of covariate TERRAIN.             |
| A(4)=0.2072   | 0.1142         | Coefficient of the adjustment term of order 2 |
| f(0)= 0.36997 | 0.05556        |   |

Total Chi-square value = 5.8453 Degrees of Freedom = 9

Probability of a greater chi-square value, P = 0.75530

**Investigation into Qa'a detection function:**

The number of droppings encountered in the 1.0-2.0m bin is substantially lower than expected (Fig. 3.4). This bin is in the immediate vicinity of both the observer and the recorder, and it seems unlikely that observers overlooked droppings in this bin. A careful look at the data revealed that there 12 observations were recorded at 0.00 distance from the rope. It is likely that at least some of these were probably further from the track line or more probably is caused by excess observations at 2.5-3.0m distance.

Three possible scenarios may have affected the detection probability for the observers: 1) on some types of terrain, particularly on the gravel plains, the gravel is similar to droppings in size, shape and colour; 2) on the boulder fields some droppings may be hidden by rocks and therefore not detected; 3) the observer may have involuntarily drawn towards dung pellets that were close to the survey line and which he could see ahead, this could result in some observations being placed in the 0.0-1.0m bin instead of the 1.0-2.0m bin.

The first two scenarios could be tested by fitting a separate detection function to observations from the gravel plain and boulder fields terrains and comparing this to the detection function from all terrains. If these are significantly different a separate sampling protocol will need to be devised for these terrains types in future surveys.

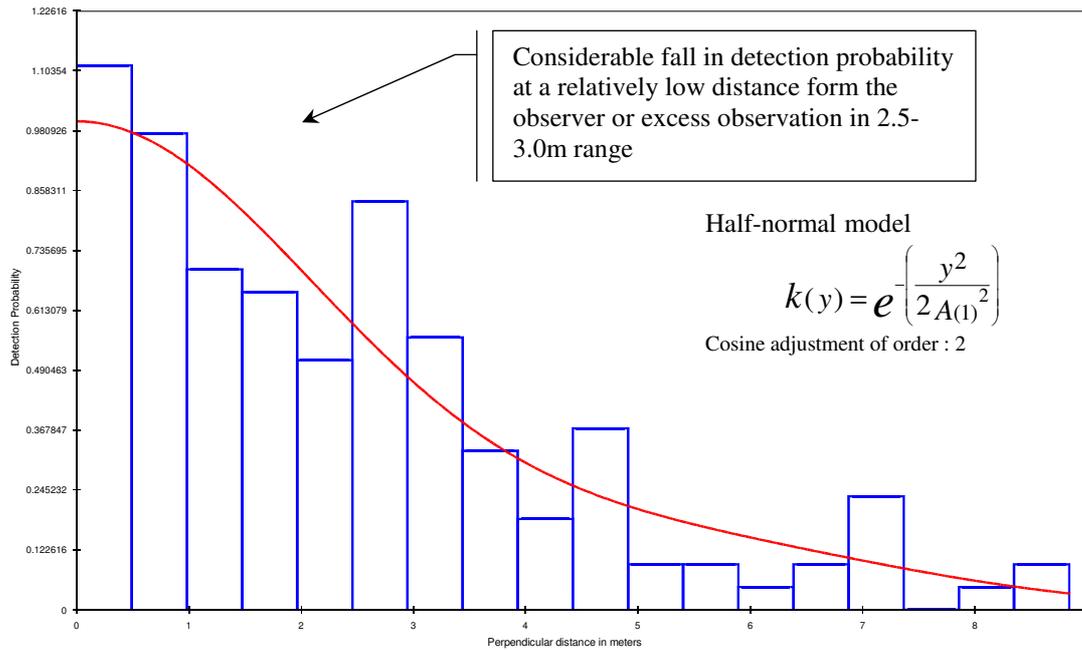


Fig. 3.4 Global detection function plot fitted for all types of terrain.

**Detection functions for gravel plain and boulder field and other terrain types:**

In order to compare the two detection functions, all the treatments affecting the data sets were kept constant for the two runs, i.e. the model was fitted using the same interval cut points and with the data truncated at 6.0m. Interval cut-points used are listed in Table (3.5).

Table 3.5 Interval cut points used for detection functions in gravel plain and boulder field terrains

| Cell | I | Cut Points  | Observed | Expected | Chi-square |
|------|---|-------------|----------|----------|------------|
| 1    |   | 0.00 0.465  | 16.0     | 17.31    | 0.100      |
| 2    |   | 0.465 0.931 | 19.0     | 16.79    | 0.291      |
| 3    |   | 0.931 1.40  | 14.0     | 15.82    | 0.209      |
| 4    |   | 1.40 1.86   | 12.0     | 14.06    | 0.302      |
| 5    |   | 1.86 2.33   | 9.0      | 12.60    | 1.027      |
| 6    |   | 2.33 2.79   | 16.0     | 10.46    | 2.930      |
| 7    |   | 2.79 3.26   | 11.0     | 8.78     | 0.562      |
| 8    |   | 3.26 3.72   | 7.0      | 6.83     | 0.004      |
| 9    |   | 3.72 4.19   | 5.0      | 5.37     | 0.025      |
| 10   |   | 4.19 4.65   | 2.0      | 3.91     | 0.933      |
| 11   |   | 4.65 5.12   | 5.0      | 2.88     | 1.566      |
| 12   |   | 5.12 5.58   | 1.0      | 1.96     | 0.472      |
| 13   |   | 5.58 6.00   | 1.0      | 1.23     | 0.045      |

Total Chi-square value = 8.4644 Degrees of Freedom = 11  
 Probability of a greater chi-square value, P = 0.67120

Figure (3.5) shows the fitted detection function for gravel plain / boulder field terrain types while model fit parameters and point estimates of (*f*) are listed in table (3.6)

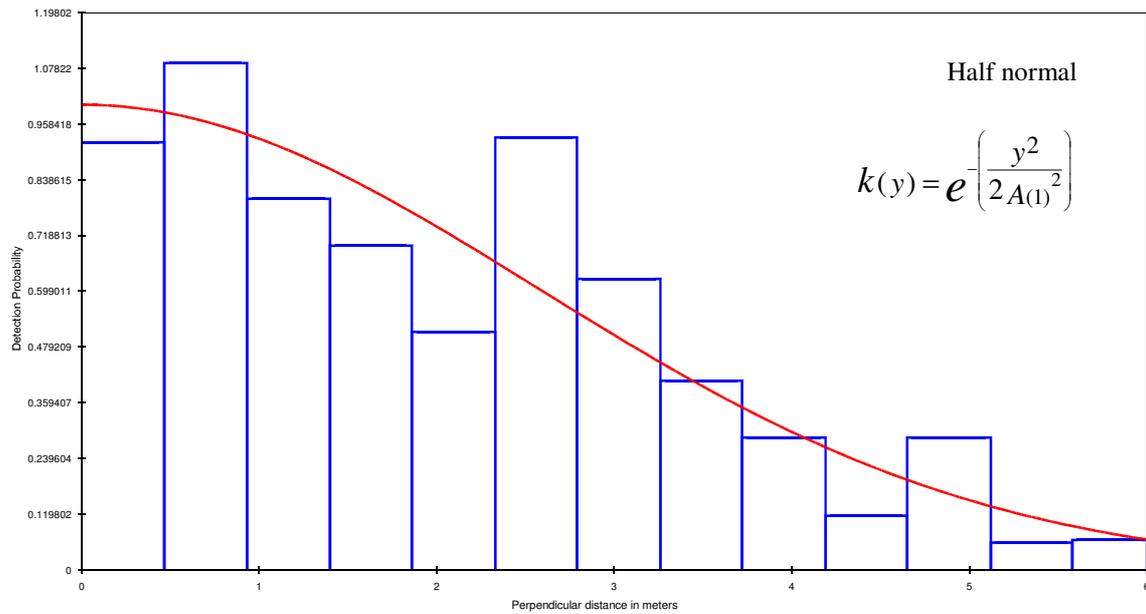


Fig 3.5 Detection function fitted to data for gravel plain and boulder field types of terrain.

Table (3.6) Model fit parameters and point estimates of gravel/ boulder field detection function

**Model: Half-normal**  $k(y) = e^{-\left(\frac{y}{A(1)}\right)^2}$

| Parameter | Point Estimate | Standard Error | CV%  | 95 Percent Confidence Interval |         |
|-----------|----------------|----------------|------|--------------------------------|---------|
| A ( 1)    | 2.609          | 0.2033         | 7.80 |                                |         |
| f (0)     | 0.31256        | 0.021120       | 6.76 | 0.27356                        | 0.35713 |

Effort : 76.3790 km  
 No. of samples : 57  
 Width : 6.0m  
 No. of observations : 118  
 Combined Estimates:  
 Half-normal/Cosine

|       | Estimate | %CV  | df  | 95% Confidence Interval |         |
|-------|----------|------|-----|-------------------------|---------|
| M     | 1.0000   |      |     |                         |         |
| AIC   | 516.03   |      |     |                         |         |
| Chi-p | 0.82138  |      |     |                         |         |
| f(0)  | 0.31256  | 6.76 | 160 | 0.27356                 | 0.35713 |
| p     | 0.53323  | 6.76 | 160 | 0.46668                 | 0.60926 |
| ESW   | 3.1994   | 6.76 | 160 | 2.8001                  | 3.6556  |

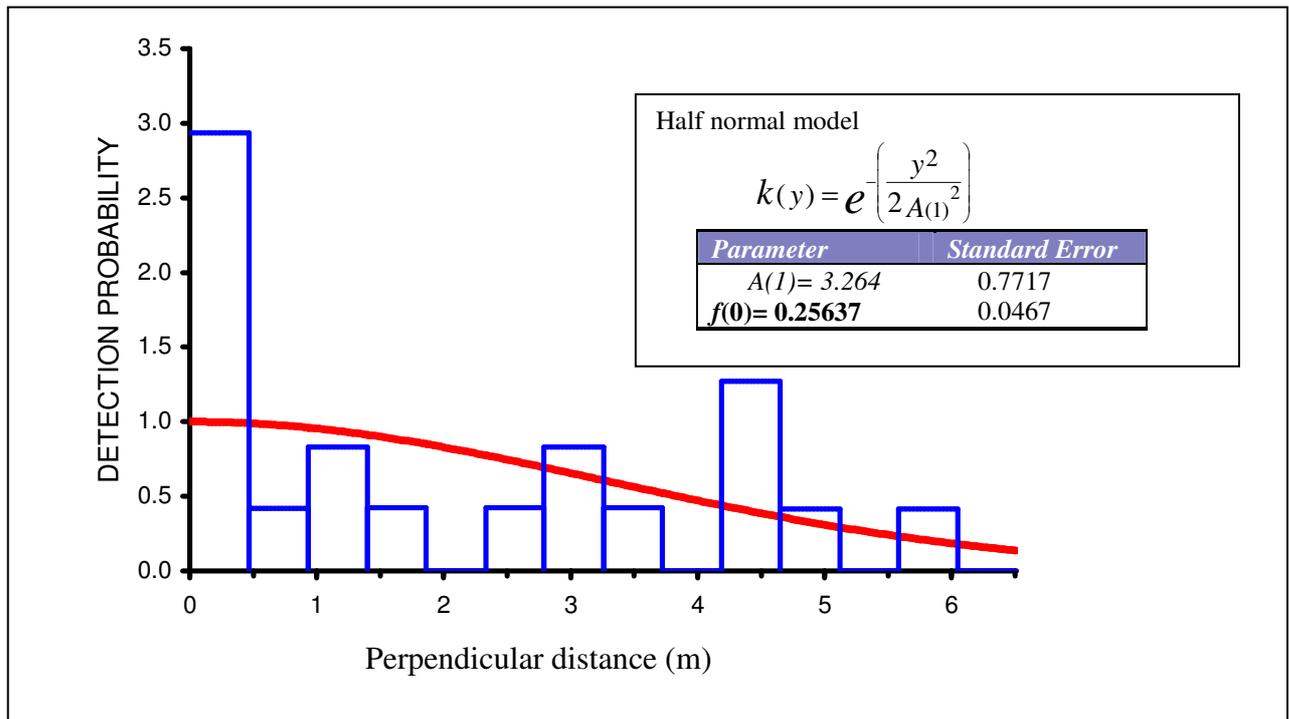


Fig 3.6 Detection function fitted to all other types of terrain.

The detection function fitted to the observations from the gravel plains and boulder fields allows us to dismiss scenario 1 (failure to detect droppings >1m from the transect line because of their similarity to stones) as a possible explanation for the rapid decline in encounters observed between 1 and 2m from the transect line. However, the data from the “other terrains” show a very dramatic drop in the number of encounters between 0.5 and 1.0m from the transect line as shown in figure (3.6). Although this could be a consequence of scenario 2 (inadvertent deviations of the transect line towards piles of droppings), this scenario should have affected the detection functions for both habitat types.

The observed values of the AIC statistics can be used to judge whether to use one global detection function for all terrains or to use separate detection function for the gravel plains and boulder fields and another detection function for all other terrain types. Since AICs are only comparable when applied to the same set of data, the three data sets (global, gravel plain and boulder fields, and other terrain types) were truncated to 6.5 m. The sum of the AIC for the gravel and

boulder detection function and the AIC for other terrains is compared with the AIC for the global detection function:

$$AIC_{global} = 457.750, \quad AIC_{gravel \& boulder} = 386.780 \quad \& \quad AIC_{others} = 71.858$$

$$AIC_{global} = 457.750 < AIC_{summed} = 458.638$$

These results suggest that a single global function provides a better explanation of the observed variation in the data than the use of separate detection functions for the two habitat types, and this is the approach that has been adopted for the rest of this thesis. However, the data from the “other terrains” is clearly a very poor fit to a half normal model, showing a very rapid decline in encounter rate beyond 0.5m from the transect line, and then very little change beyond that distance. It is conceivable that a different form of detection function would provide a better fit to these data and reduce the AIC for this dataset. This will be explored at a later date.

From the previous investigation the following scenario is most probable; the plots of the three different detection functions shown in figure (3.7) the problem is caused by too many observations right on the track line in “all other habitats” with more normal observations in the gravel plain and boulder fields habitats with the exception of the 2.0-3.0m distance which have relatively higher number of observations. So what could have happened that observers in ‘other habitats’ focus on the track line and only occasionally detecting droppings away from it, whereas they behave perfectly in the gravel plains and boulder fields producing what look much like standard line transect data. Knowing the that gazelle prefers these types of habitats (gravel plains and boulder fields) where they are relatively more droppings to detect makes it easy for the observers to be continuously alert and looking somewhat more away from the track-line yielding standard looking data.

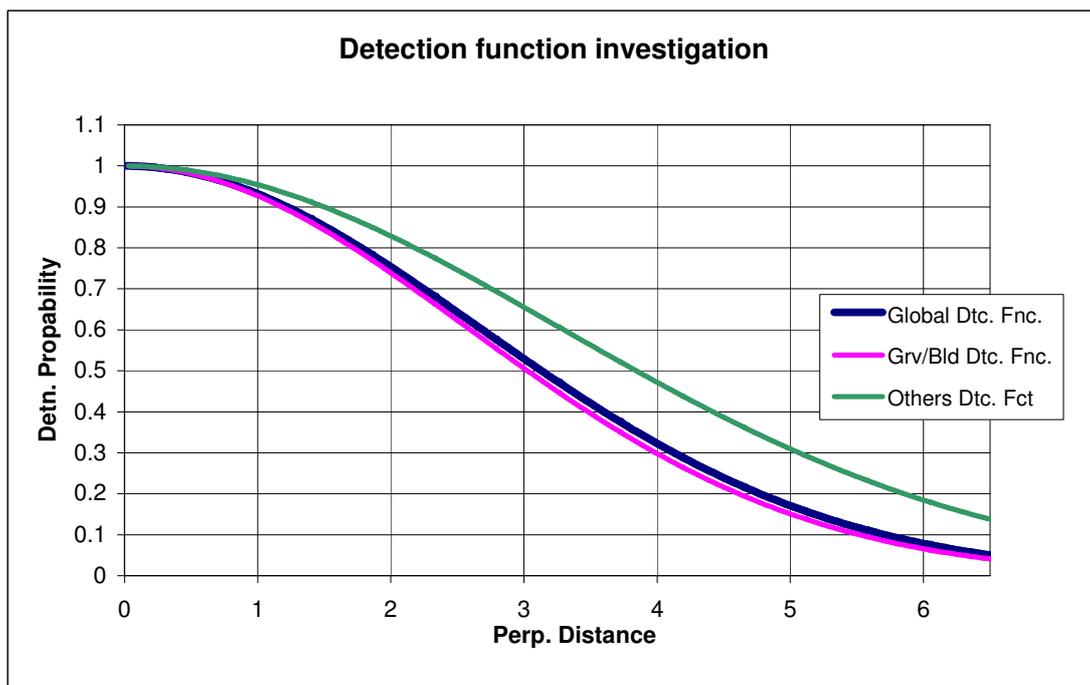


Fig 3.7 The three detection functions superimposed.

Although the results for density estimates in the current study adopts MCDS incorporating covariates into detection function, investigation was made to compare results with conventional distance analysis with no covariates in Qa'a plain. The target is to assess whether is it a sound practice to use multi-covariate analysis? or is it better to stick to the conventional model fitting the detection function?

Akaike information criterion was also used to compare the two models. Using the same interval cut-points and Half normal model and truncation at 6.5 m gave results listed in table (3.7).

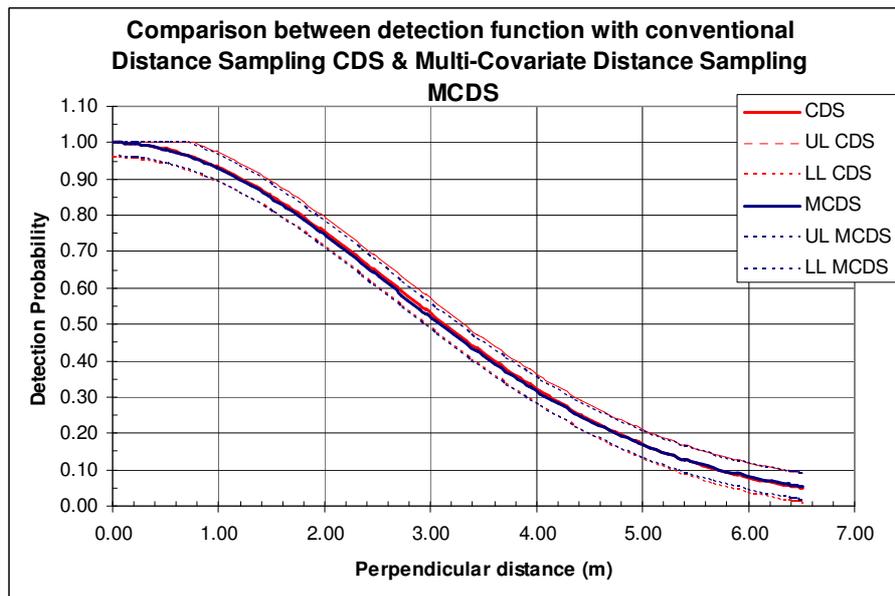
Table (3.7) Fits parameters comparing detection function using CDS & MCDS for Qa'a plain.

| Model | AIC     | Detection function ( $f$ ) | CV%  | 95 Percent Confidence Interval |        |
|-------|---------|----------------------------|------|--------------------------------|--------|
| CDS   | 457.747 | 0.304                      | 6.83 | 0.2660                         | 0.3484 |
| MCDS  | 459.890 | 0.307                      | 6.11 | 0.2718                         | 0.3460 |

The test shows that CDS detection function is a better model for fitting the detection function with lower AIC. However, AIC attempts to trade off reducing bias by adding more parameters vs. increasing variance and model complexity. The formula  $AIC = (-2\log_e L) + 2q$ , where  $L$  is the likelihood

and  $q$  is number of parameters. The first part ( $-2\log_e L$ ) is interpreted as a measure of how well the model fitted the data and the second part as a penalty for adding parameters. In this case adding the two covariates has improved the model fit with a reduced ( $-2\log_e L$ ) but not enough to overcome the  $2q$  penalty of adding two parameters. Thus, it could be seen that adding covariates has reduced bias in estimating the detection function. Although covariates have effect, it seems to be a weak one which is illustrated by the high standard error in point estimates of the coefficients of covariates habitat and terrain. Moreover, there is no significant differences between the values of the two point estimates of ( $f$ ) in both cases. Also the same is expressed by their confidence limits where both are lying approximately in the same interval. Plotting the two detection functions in figure (3.8) shows the strong resemblance of the two functions.

Fig (3.8) The CDS & MCDS detection functions compared.



In the light of these findings it is decided to adopt the MCDS approach as covariates (terrain & habitat) are intuitively expected to radically affect the detection function.

### 3.1.2-Detection function for Nabaq area.

In the Nabaq study area only 5 dropping piles were detected. There are two possible approaches. The first is to pool the observations of Nabaq. The second is to pool observations from the current surveys with observations from previous surveys carried out in the Nabaq area in December 1999 and May 2000 by the St Katherine Protectorate Management Unit.

The habitats and type of terrain in Nabaq are very different from those on the Qaa plain, thus the detection functions are also likely to be very different. For this reason, the second approach was adopted.

A global detection function was fitted to the three sets of data, but density and abundance were estimated separately for each year separately to obtain a value for the current survey. Only the latest value for Nabaq is reported in this context. Nabaq detection function is shown in figure (3.9)

Data were truncated at 6.5 m. As for the Qaa plain study area, cosine, simple polynomial and hermite polynomial adjustment terms were tested with the hazard rate and the half-normal functions. Results are shown in Table 3.8.

Table (3.8) Key functions used to fit detection function for Nabaq area.

| Key function | Adjustment term    | No. of parameters | AIC value |
|--------------|--------------------|-------------------|-----------|
| Half-normal  | Cosine             | 1                 | 161.20    |
| Half-normal  | Simple polynomial  | 1                 | 161.20    |
| Half-normal  | Hermite polynomial | 1                 | 161.20    |
| Hazard rate  | Cosine             | 2                 | 164.86    |
| Hazard rate  | Simple polynomial  | 3                 | 162.87    |
| Hazard rate  | Hermite polynomial | 3                 | 163.42    |

All of the half-normal functions results in lower AIC values than any of the hazard rate functions. However, adding adjustment terms did not reduce the AIC. On this basis the half-normal function, without adjustment, was chosen as the model for the Nabaq detection function.

Interval cut points and goodness of fit parameters are listed in Table 3.9 and point estimates with model parameters are listed in table (3.10)

Table 3.9 Interval cut points used for Nabaq study area

| Cell I | Cut Points |       | Observed | Expected | Chi-square |
|--------|------------|-------|----------|----------|------------|
| 1      | 0.00       | 0.650 | 11.0     | 11.04    | 0.000      |
| 2      | 0.650      | 1.30  | 11.0     | 10.25    | 0.055      |
| 3      | 1.30       | 1.95  | 9.0      | 8.84     | 0.003      |
| 4      | 1.95       | 2.60  | 5.0      | 7.08     | 0.611      |
| 5      | 2.60       | 3.25  | 5.0      | 5.27     | 0.013      |
| 6      | 3.25       | 3.90  | 5.0      | 3.64     | 0.511      |
| 7      | 3.90       | 4.55  | 3.0      | 2.33     | 0.191      |
| 8      | 4.55       | 5.20  | 2.0      | 1.39     | 0.269      |
| 9      | 5.20       | 5.85  | 0        | 0.77     | 0.768      |
| 10     | 5.85       | 6.5   | 0        | 0.39     | 0.395      |

Total Chi-square value = 2.8161 Degrees of Freedom = 8.0

Probability of a greater chi-square value, P = 0.94536

### Model Parameters:

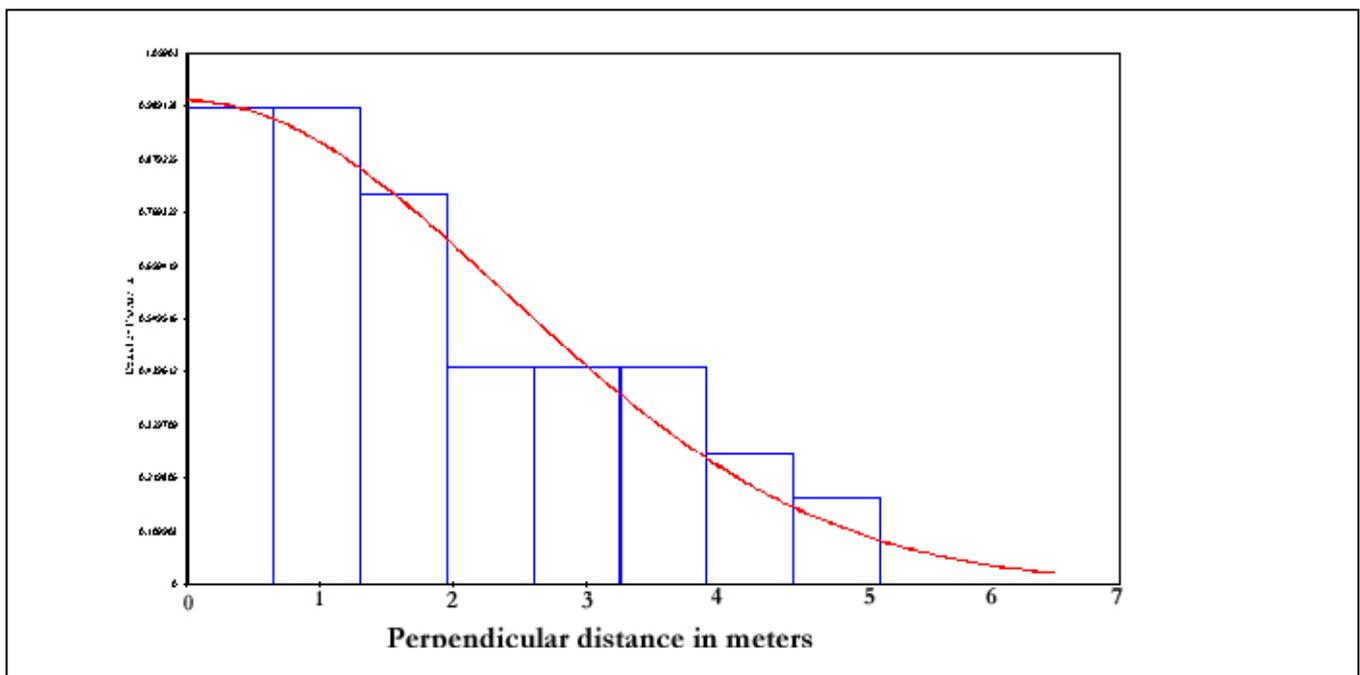
Half normal key function

$$k(y) = e^{-\left(\frac{y^2}{2A(1)^2}\right)}$$

table (3.10) point estimates and model parameters of Nabaq detection function model fitting

| Parameter | Point Estimate | Standard Error | CV%   | 95 Percent Confidence Interval |         |
|-----------|----------------|----------------|-------|--------------------------------|---------|
| A(1)      | 2.382          | 0.284800       | 11.96 |                                |         |
| f(0)      | 0.337          | 0.038195       | 11.33 | 0.26875                        | 0.42300 |

Fig 3.9 Detection function used in Nabaq study area



### 3.2-Density Estimates

Dung density was estimated using the detection functions described in section 3.1 both globally and per stratum (Table 3.11). The global density estimate is the mean of the per stratum estimates weighted by the stratum area.

Table (3.11) Gazelle dung density estimates (dropping/km<sup>2</sup>)

| Stratum                  | Density | CV     | 95% confidence interval limits |      |
|--------------------------|---------|--------|--------------------------------|------|
| Qaa high density stratum | 638     | 38.4%  | 299                            | 1360 |
| Qaa low density stratum  | 5       | 103.2% | 1                              | 29   |
| Entire Qaa Plain         | 222     | 37.9%  | 105                            | 470  |
| Nabaq area               | 14      | 65.0%  | 4                              | 48   |

### 3.3 - Estimating variance in encounter number $var(n)$

A good survey design should guarantee more or less uniform encounter rate of dung along each transect line over each stratum of the survey. That is, the expected encounter rate for a stratum should approximate the average encounter rate of all transect lines within this stratum; mathematically :

$$E_v\left(\frac{n_v}{l_v}\right) \approx \bar{\mu}_v \quad \text{where } \bar{\mu}_v \text{ is the mean encounter rate for stratum } v$$

If the above formula holds, then the variance in the number of droppings encountered can be estimated from the formula:

$$\hat{var}(n) = L \frac{\sum_{i=1}^k l_i \left(\frac{n_i}{l_i} - \frac{n}{L}\right)^2}{k-1} \dots\dots\dots(3,1)$$

If the assumption does not hold, then the survey design may have to be altered, for example through stratification; orientation of survey lines perpendicular to density contours, or adjustment of transects lengths.

The expected and mean observed encounter rates over all line replicates in both the high density and the low density strata for Qaa plain are shown in table 3.12

Table3.12 Expected and observed encounter rates over all line replicate in different strata for Qa'a plain

| Stratum          | $E\left(\frac{n}{L}\right)$ | $\bar{\mu}_v$ |
|------------------|-----------------------------|---------------|
| Qaa high density | 3.70018                     | 3.6907        |
| Qaa low density  | 0.03225                     | 0.04411       |

The assumptions of the method appear to be met satisfactorily. Calculated values for the variance in encounter rate in the two strata for the Qa'a plain are shown in table (3.13).

Table 3.13 Estimated variance in the number of encounters for high and low density strata in Qaa plain

| Stratum          | var( <i>n</i> ) | S.D.  |
|------------------|-----------------|-------|
| Qaa high density | 2553.547        | 50.53 |
| Qaa low density  | 1.3819          | 1.175 |

It is apparent that there is a real problem with the variance in the high-density stratum. There are two sources of variance that are contributing to the estimated variance. The first is the residual (stochastic) variation in number of droppings found along each line transect; the second is the structural variation which is attributed to the geographical location of each line transect.

If the gazelle droppings are aggregated within a relatively small portion of the study area, this will result in a high variability in the number of droppings encountered among transects. This variance can be reduced by defining new strata with a more homogeneous occurrence of droppings

The contribution of the structural component to the variance can be illustrated by addressing the dispersion parameter (*b*). If the data are stratified into *V* strata and within each stratum there are *k* line replicates, then any replicate can be identified as *l<sub>vj</sub>* *j*=1,.....,*k<sub>v</sub>* , *v*=1,.....,*V*. The variance in the number of encounters within each stratum is obtained from :

$$\hat{\text{var}}(n_v) = L_v \frac{\sum_{i=1}^k l_{iv} \left( \frac{n_{iv} - n_v}{l_{iv} - L_v} \right)^2}{k_v - 1} \dots\dots\dots \text{where } L_v = \sum l_{vi}$$

The dispersion parameter within each stratum (*b<sub>v</sub>*) is

$$\hat{b}_v = \frac{\hat{\text{var}}(n_v)}{n_v}$$

and for the entire survey area

$$\hat{b} = \frac{\sum_{v=1}^V \widehat{\text{var}}(n_v)}{\sum_{v=1}^V n_v} = \frac{\sum_{v=1}^V n_v \hat{b}_v}{\sum_{v=1}^V n_v}$$

If droppings have a homogenous, Poisson distribution within a stratum, then  $b$  is expected to equal 1. However, most biological systems tend to cluster, so  $b > 1$  is expected.  $b$  values for the area under investigation are shown in Table 3.14.

Table 3.14 Estimates of the dispersion parameter ( $b$ ) for Qaa plain surveys

| Stratum           | $b$    | $n$ . |
|-------------------|--------|-------|
| Qaa high density  | 17.253 | 148   |
| Qaa low density   |        | 1     |
| Overall Qaa plain | 17.144 | 149   |

These values suggest that there is a strong clustering of gazelle droppings in the high density stratum. In fact, even within this stratum, many of the transects have no encounters, while some have up to 46 observations. Most of the encounters occurred in the southern region, while most of the blank transects were in the northern region (Fig. 3.10). Although the dispersion parameter can be reduced, especially in the northern region, by further stratification, values remain very high (table 3.15). The difference in ( $b$ ) is so small between southern part of the high density stratum and the entire stratum may be to low number of detections (only 6) in the northern part.

Table 3.15 Estimates of the dispersion parameter ( $b$ ) for the Qaa plain after further stratification

| Stratum                      | $b$     | $n$ |
|------------------------------|---------|-----|
| <i>Southern</i> high density | 16.6129 | 142 |
| <i>Northern</i> high density | 8.746   | 6   |
| Low density                  | 1.0418  | 1   |
| Overall Qaa plain            | 16.3010 | 149 |

The equivalent results for the Nabaq study area are shown in Table 3.16. Droppings appeared to be randomly distributed in the high density stratum, but more regularly distributed in the low density stratum ( $b < 1$ ).

Table 3.16 Estimates of the dispersion parameter ( $b$ ) for the Nabaq study area

| Stratum            | $b$    | $n$ . |
|--------------------|--------|-------|
| Nabaq high density | 1.2043 | 4     |
| Nabaq low density  | 0.6611 | 1     |
| Overall Nabaq Area | 1.0957 | 5     |

However, only five droppings were encountered in the entire survey, so these results must be interpreted with caution.

### **3.3- Estimation of variance in density.**

To calculate the variance of the density estimates we must evaluate all components of variance contributing to the density estimate. These are variance in number of observations detected in each line, variance in the parameters of the detection function, and variance in the probability of detecting a dropping on the transect line. These elements can be formulated as :

$$\hat{\text{var}}(\hat{D}) = \hat{D}^2 \cdot \left\{ \frac{\hat{\text{var}}(n)}{n^2} + \frac{\hat{\text{var}}[f(0)]}{[f(0)]^2} + \frac{\hat{\text{var}}[g(0)]}{[g(0)]^2} + \frac{\hat{\text{var}}[E(s)]}{[E(s)]^2} \right\}$$

It is assumed that all droppings on the transect line are detected and that perpendicular distances are recorded from individual objects and not clusters. Thus, the terms  $\frac{\hat{\text{var}}[g(0)]}{[g(0)]^2}$  &  $\frac{\hat{\text{var}}[E(s)]}{[E(s)]^2}$  can be omitted from the equation. The program “Distance”

provides estimate of variance of  $f(0)$ , which leaves only one component  $\hat{\text{var}}(n)$  to be estimated. Since this is a stratified survey, a slight modification is added to the formula, which becomes:

$$\hat{\text{var}}(\hat{D}) = \hat{D}^2 \cdot \left\{ \frac{\hat{\text{var}}(\hat{M})}{\hat{M}^2} + \frac{\hat{\text{var}}[f(0)]}{[f(0)]^2} \right\}$$

$$\text{where } \hat{M} = \frac{\sum_v A_v \hat{M}_v}{A^2} \quad \text{and} \quad \hat{\text{var}}(\hat{M}) = \frac{\sum_v A_v^2 \hat{\text{var}}(\hat{M}_v)}{A^2} \quad \text{with}$$

$$\hat{\text{var}}(\hat{M}) = \hat{M}_v^2 \cdot \left\{ \frac{\hat{\text{var}}(n_v)}{n_v^2} + \frac{\hat{\text{var}}[\bar{s}_v]}{\bar{s}_v^2} \right\} \text{ where } s \text{ is the estimated cluster size, again this}$$

equation becomes  $\hat{\text{var}}(\hat{M}) = \hat{M}_v^2 \cdot \frac{\hat{\text{var}}(n_v)}{n_v^2}$  since perpendicular distances are

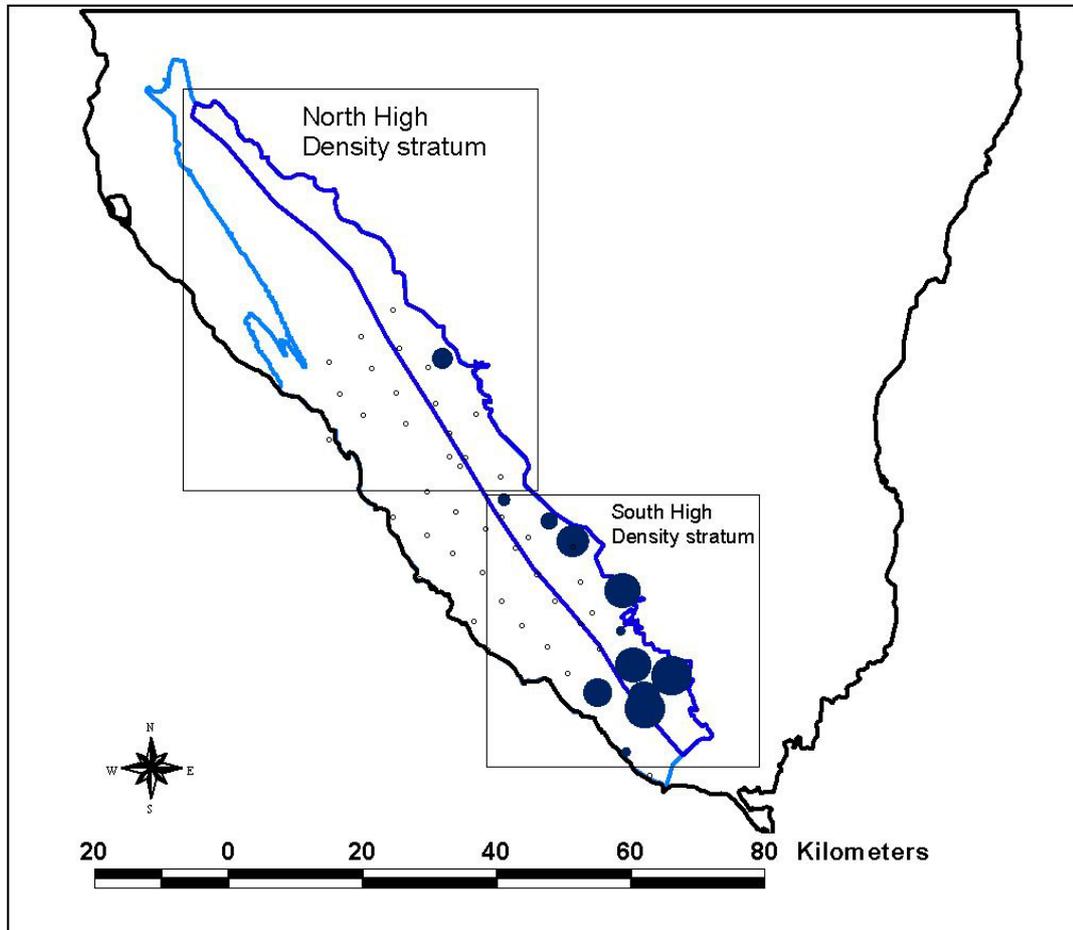
measured to individual pellet groups and not to clusters.

and  $\hat{M}_v = \frac{n_v \times \bar{s}_v}{k_v}$  where  $n_v$  is the number of detections in stratum  $v$ ,  $s_v$  is the

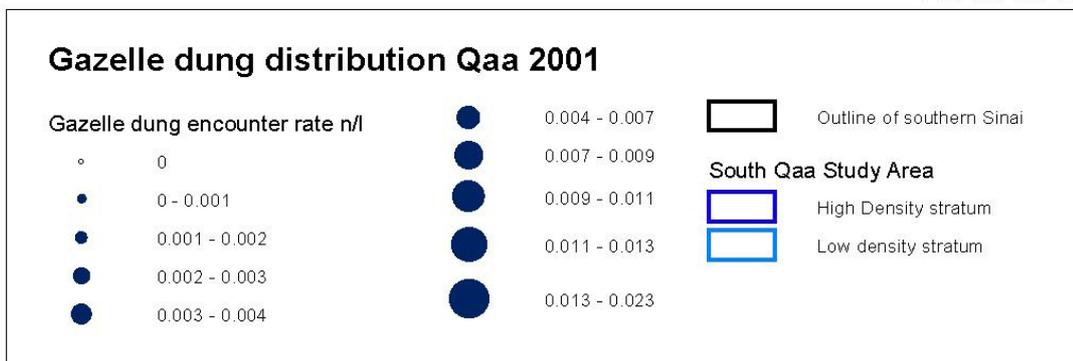
estimated cluster size in stratum  $v$  and  $k_v$  is number of transects in stratum  $v$ .

Incorporating all of these elements, the overall variance in the density estimate is calculated to be 2881096, giving a standard deviation of 1697.4.

Figure 3.10 Distribution of transects with and without droppings in the high density stratum of the Qaa plain study area and the high density stratum.



1:900000



### **3.4- Spatial distributions of droppings.**

Kriging was used to interpolate values of camel and gazelle dropping encounter rates between transects to obtain an estimated distribution for the entire Qaa plain study area. Kriging uses the auto-correlation between values to estimate encounter rates in unsurveyed areas, no information about environmental factors underlying the distribution is involved in the model. Kriging is a method to interpolate point data, while the estimated dropping encounter rates are associated with transect lines, thus the geometrical center of the line was used for kriging. Figure 3.12 shows that gazelles and camels appear to be using the study area differently.

The Cramer von Mises statistic,  $W_n^2$  can be used to measure the level of agreement between the distribution of gazelle droppings ( $G_n(x)$ ) and camel droppings ( $F_X(x)$ )

$$W_n^2 = n \int_0^1 [G_n(u) - u]^2 du$$

This statistic is used to test the null hypothesis that droppings of the two species are distributed in a similar way over the plain [ $H_0: G_n(x) = F_X(x)$ ]. The encounter rates with camel and gazelle droppings were used to describe these distributions. The ordered individual encounter rates of transects are used to calculate the statistic  $\Gamma$  :

$$\Gamma = \left( \frac{n_1 \times n_2}{(n_1 + n_2)^2} \right) \times \sum_{i=1}^n (S_{1i} - S_{2i})^2$$

where :

$S_1$  is the first event (gazelle dung encounter rate) &  $n_1$  number of transects used to assess event 1

$S_2$  is the second event (camel dung encounter rate) &  $n_2$  number of transects used to assess event 2

The two cumulative distribution functions are shown in Fig. 3.11. The null hypothesis is rejected if  $\Gamma > W_{0.05} = 0.461$ . The calculated value of  $\Gamma$  for Qaa plain is 5.444, and thus it is concluded that the spatial distribution of gazelle droppings is significantly different from that of camels'.

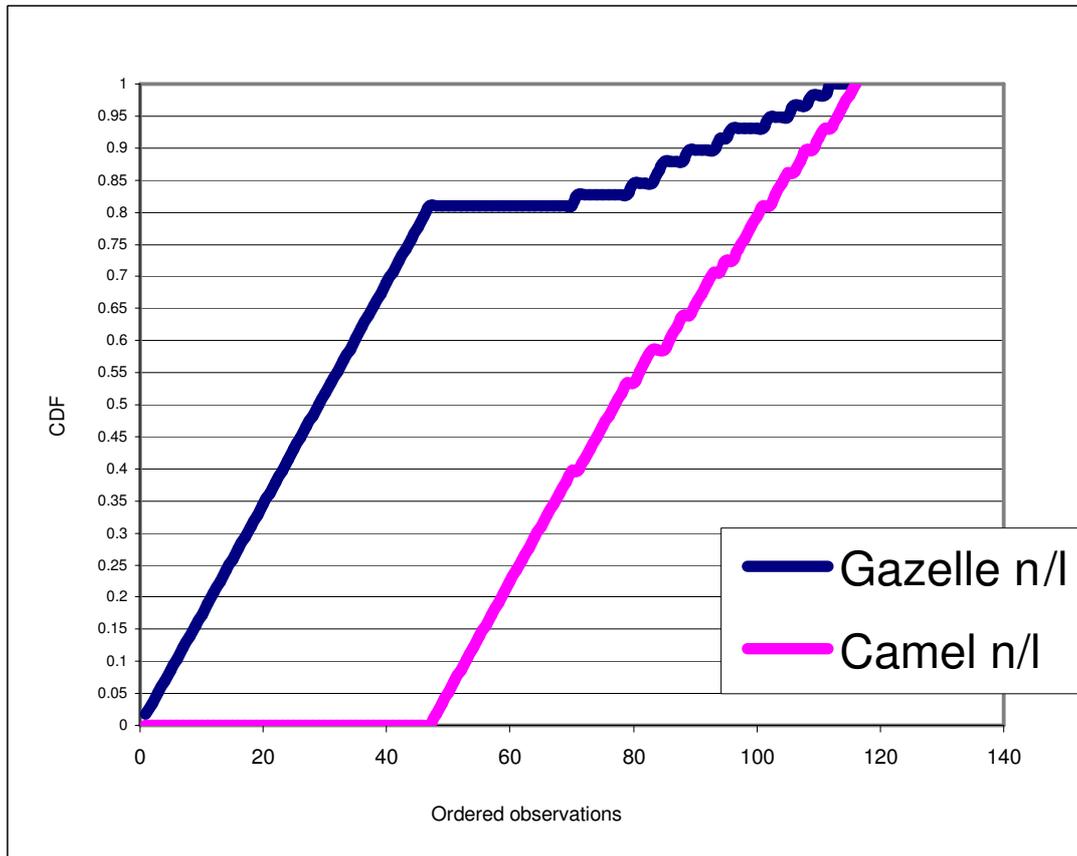
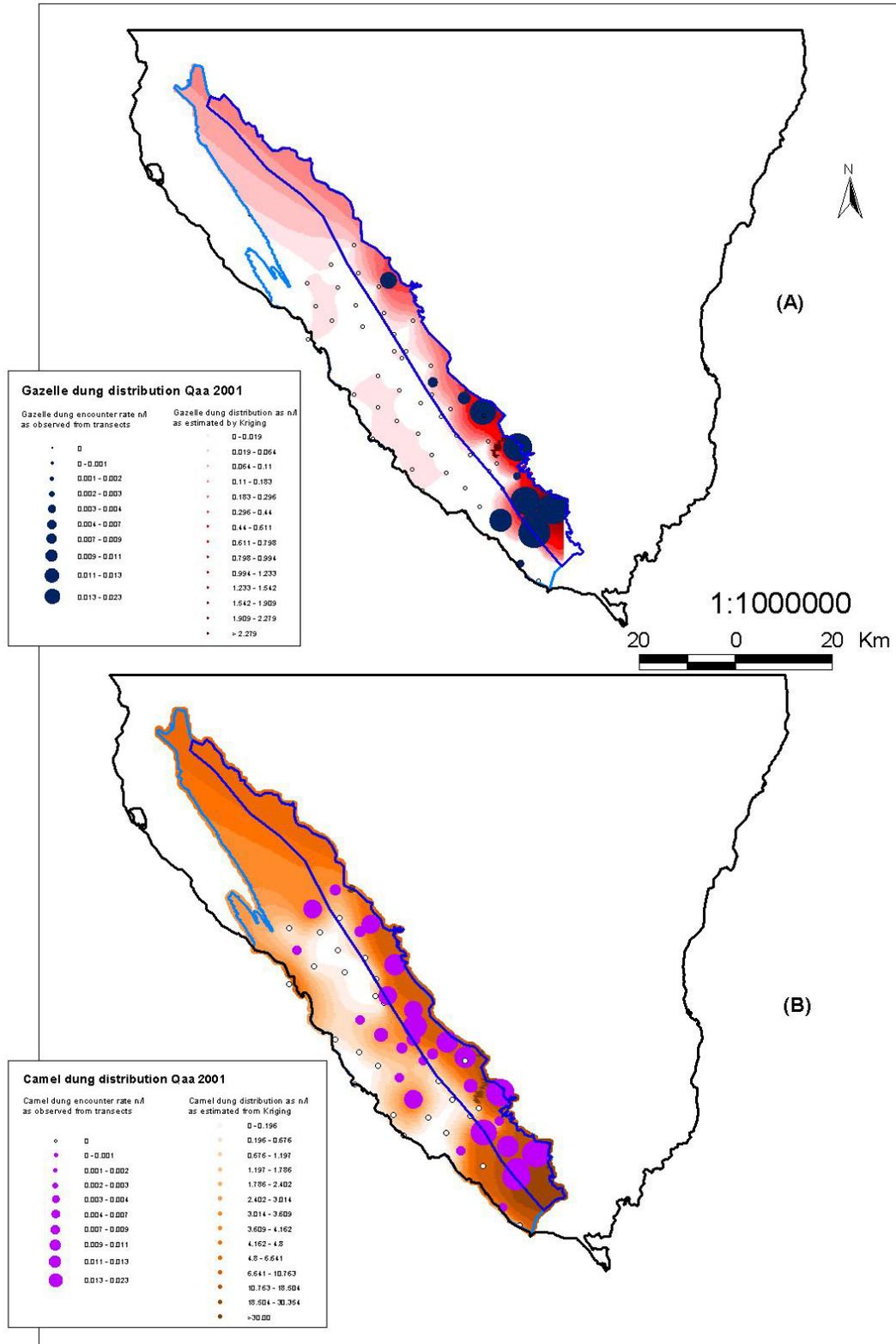


Fig. 3.11 Cumulative frequency distribution of encounters with camel and gazelle droppings in Qa'a Plain.

Figure 3.12 Predicted distribution of encounter rate with gazelle (A) and camel (B) droppings over the entire Qa'a Plain. Actual encounters are shown by circles



### **3.5- Estimating dropping decay rate.**

As described in Chapter 2, five plots were installed in the Qa'a plain to investigate how rapidly droppings decayed. The initial number of gazelle droppings in each plot was recorded. Plots were revisited on a monthly basis and the number of pellets lost since the previous count was recorded as a percentage ( $100 \times [1 - \text{current count} / \text{preceding month's count}]$ ) . .

The plots were observed for 15 months. There was no change in pellets number until the 7<sup>th</sup> month, when some decline was observed in plots 3 and 4. Terrain appeared to affect the decay rate; plots in the sandy habitat showed faster decay than those in much gravelly areas (Fig. 3.13). Plot 1, which is in totally sandy terrain, showed 100% decay after 15 months while in plots 4 and 5, which are in gravelly terrain, the decay was less than 50%.

Data from the five plots were pooled and 2 methods of smoothing -namely; spline smoothing and local regression- were tested to predict the decay rate of gazelle droppings.

Spline smoothing has a theoretical justification that can be used to determine the appropriate smoothness for the fit. Smoothing splines are locally cubic splines that minimize a penalized residual sum of squares, drawing a smoothed curve through the data points. When degree of freedom was selected automatically using cross-validation the resulting line showed big amount of wiggleness thus 3 was specified as a selected degree of freedom.

Local regression is a nonparametric smoothing technique. It is a generalization of running means, which gets a predicted value at each point by fitting a weighted linear regression, where the weights decrease with distance from the point of interest. Connecting these predicted values produces a smooth curve. The primary parameter affecting the smoothness of the fit is the span, which controls the speed with which the influence of points decreases with distance from the point of interest.

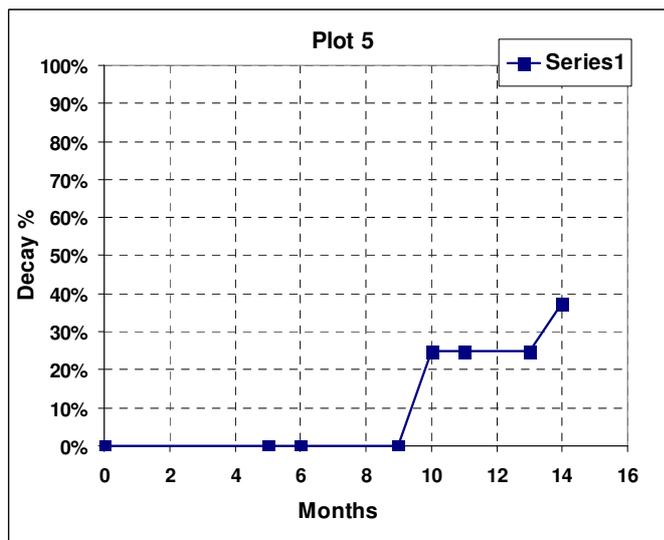
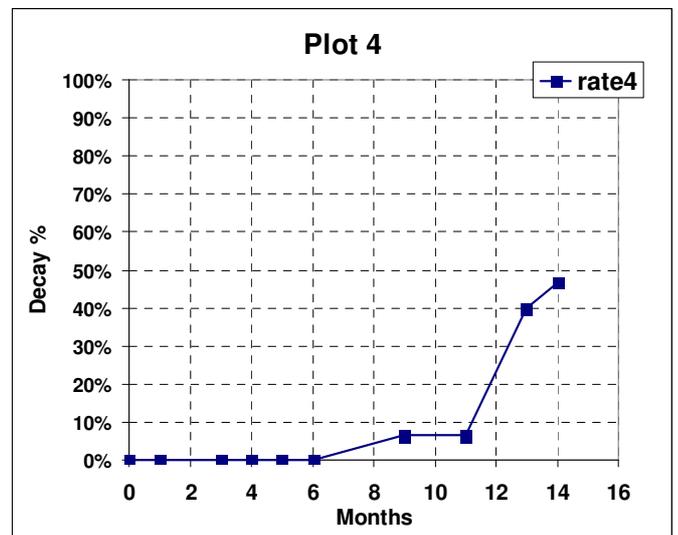
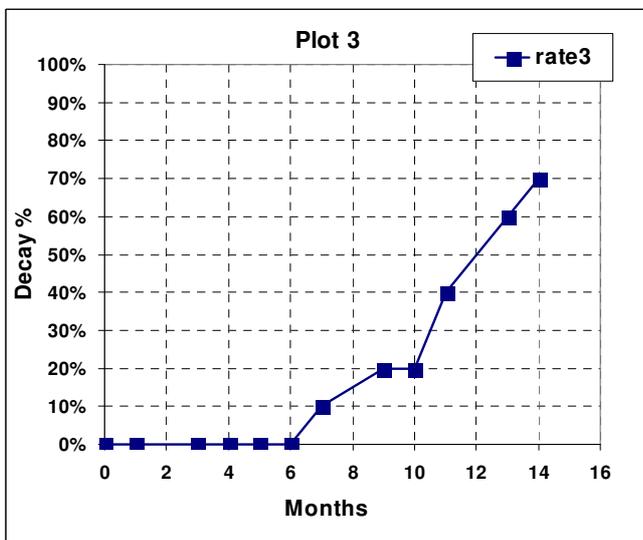
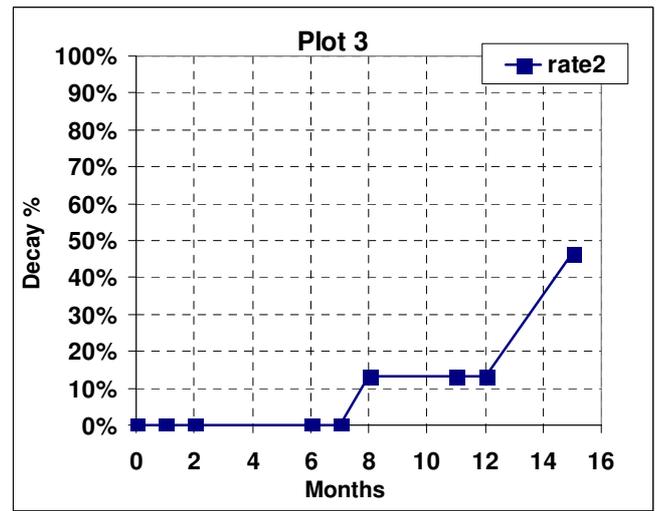
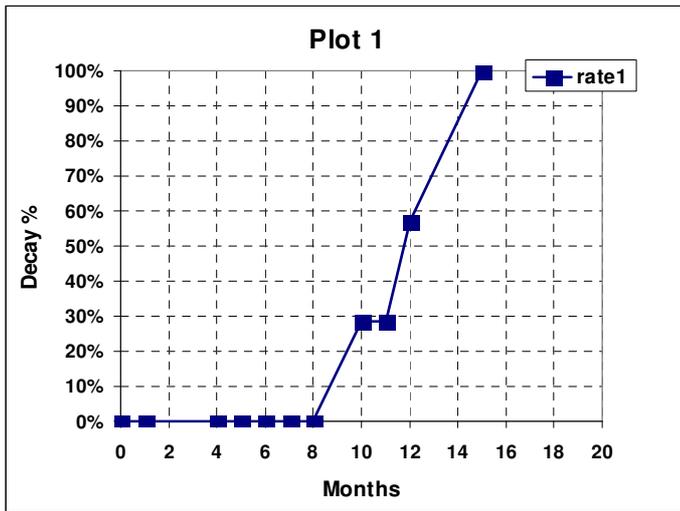


Fig (3.13) Showing the dung decay rate over a period of 15 months as percentage of dung remaining on ground (y) versus age in months (x) for plots 1 to 5 in Qa'a Plain.

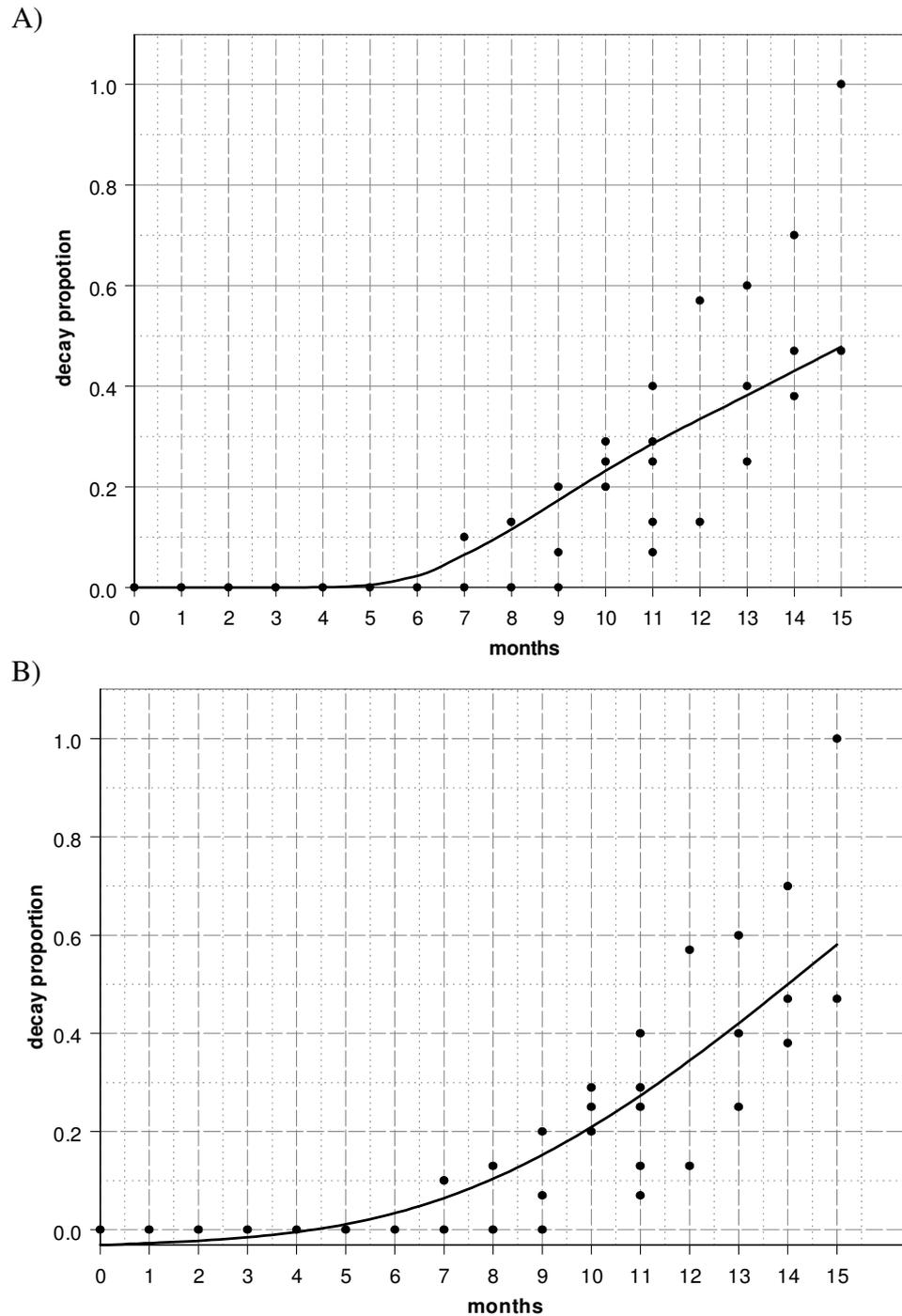


Fig 3.14 Pooled decay plot data showing fitted decay rates as A) local regression and B) spline smooth

Figure 3.14 shows that the 2 methods represented the general situation of little or no decay throughout the first six months while a prominent increase in taking place following the 8<sup>th</sup> month of observation. It is noticed that spline smooth has predicted a negative decay rate for the first four months of observation, which is totally impossible from the logical point of view. On the other hand the local regression

method is doing well concerning this point where it predicts zero decay rate for the first 5 months. There was no big difference in the decay rate predicted by the 2 methods at time point of 1.0 year. Therefore, the local regression prediction was selected over that of spline smoothing. Local regression fit has predicted an annual decay rate of 33% while the spline smoothing has predicted annual decay rate of 34%.

## **3.6- Discussion of Results**

### **3.6.1-Survey Design and Stratification.**

Results showed the conformity of the survey design and stratification scheme to the observed pattern in gazelle dung density. Only one detection was recovered in low density stratum while most of detections recorded in the high density stratum as the survey design have expected. The extent of the boundary between the high density and low density strata also succeeded in capturing the area where detections are likely to occur without including much of lower density area that , otherwise, would have consumed valuable survey effort pointlessly.

On the other hand, density estimate variance analysis showed that the current design is not the ultimate one for this region. Distribution of gazelle droppings is shown to display high clustering properties as indicated by the substantially high dispersion parameter ( $b=17.14$ ). Future surveys should adapt further stratification followed by the same approach of assessment using the dispersion parameter ( $b$ ) adopted in this study to evaluate the conformity of the stratification scheme to the spatial distribution of gazelle droppings along the study region. Better design should ensure more homogenous encounter rate per stratum.

### **3.6.2-Detection Function .**

Analysis of detection function based on data set obtained from the current study showed that the use of covariates is a significant advance in fitting the detect ability model provided that covariates are selected efficiently and are really affection observers' sight ability. However the currently selected variables and their categorization scale may be modified in future surveys since these wee observed not have that much of effect of the detection function as analysis showed. Modelling the detection function depending distance only and with covariates resulted in generally similar detection functions.

It was shown that experienced observers are an important asset to any study. Analysis of the detection function showed that certain behaviour of the observer should be addressed and rectified in future surveys to prevent ending up with biased population estimates.

**3.6.3-Decay Rate Estimation.**

Results have shown that gazelle dropping within this arid environment lasts long on the ground in a detectable status. On Average dung remained intact for a period of 6-8 months. This fact implies that an interval of one year between surveys might not be sufficient and successive surveys should be further apart in time. However, the prediction of 33 to 34% of annual dung decay provides an adjusting factor for the dung abundance and density estimates provided. The estimate of dung decay rate could be probably further enhanced by larger sample size and incorporation of environmental covariates in modelling the decay rate from observed values.

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*Chapter 4*

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**Evaluating the power of time series to detect change**

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**4.1 Introduction**

Ecological study of the population of any species aims, eventually, to provide a basis of knowledge for managing the species. Management perspectives vary according to the value of species under consideration. If the species is considered as a pest, management is towards maintaining relatively low population size. Other management schemes would aim to maintain the population at a size below its carrying capacity size, for example if the species is to be harvested to provide a sustainable yield. A popular example is fisheries management. In some cases management would have different aims throughout time for the same species. For instance, if a population is recovering from severe decline, the management plan would be shifted towards strict conservation and then re-shifted to a more relaxed attitude, such as specifying quotas for hunters, when the population is known to be re-established.

Whatever is the objective of the management scheme; managers are expected to take decisions based on information provided from monitoring efforts and field studies. Such information is the outcome of surveys that are carried out using different available methods. Sample surveys can only provide estimates not real numbers, and the error margin or uncertainty associated with these estimates is an important statistic. The decision maker may not be interested in the absolute numbers reported for any particular survey; rather he is interested in the pattern emerging from the estimates over a considerable period of time (time series). Thus, it is a crucial part of the ecological investigation to detect patterns or trends in population sizes and to provide quantification of those patterns with the highest accuracy or least uncertainty that is feasible.

The probability that a particular monitoring programme will detect patterns or trends over time is called the statistical power of the programme. Statistically, power is the probability that the null hypothesis will be rejected when it is false or the alternative hypothesis will be accepted when it is true.

## **4.2-Importance of power calculations**

The process of decision-making is normally preceded by a statistical test. In this process two hypotheses are being tested against each other using the data collected. The conservative point of view is usually termed the null hypothesis, while the other is the alternative hypothesis. The null hypothesis is rejected when the value of the test statistic is greater than a predetermined significance level. The significance level ( $\alpha$ ) is the probability of type I error (probability of rejecting a true null hypothesis). Statistical power is indicated by the significance level  $\beta$ , the probability of type II error (probability of accepting a false alternative hypothesis). Although  $\alpha=0.05$  is the generally accepted level of Type I error, there is no such standard definition of value for  $\beta$ , it depends on the individual situation and nature of the problem in hands. It is usually considered as 4 times  $\alpha$ .

The most frequent kind of power calculation is called retrospective power analysis, where the power is calculated after data have been collected. If the power calculation is done prior to the experiment, it is termed prospective power analysis. Prospective power analysis allows calculation of the appropriate sample size for experiments or surveys to detect predefined level of change. However, power analyses are often poorly reported and were, in the past, often ignored.(Peterman 1990a). Peterman (1990b) reviewed 408 fisheries papers that reported at least one failure to reject the null hypothesis, and found that only one calculated the probability of making Type II error. Taylor and Gerrodette (1987) surveyed past issues of *Conservation Biology* and found a similar lack of reporting of statistical power.

In the remainder of this chapter I will discuss how the parameters shaping any survey programme can influence the overall power of the programme to detect trends. The current survey programme in the St Katherine Protectorate will also be evaluated using the same approach.

## **4.3 Factors affecting statistical power**

In general, for any statistical test, power is a function of sample size ( $n$ ), the probability of Type I error ( $\alpha$ ), and the magnitude of the difference between the null hypothesis and reality (the effects size) (Cohen 1988). In population studies, the effect to be measured is often the change in population size ( $r$ ), which may be negative or positive. In ecological studies, population size cannot be measured precisely, and a practical

power calculation must account for the amount of uncertainty in estimating abundances. This uncertainty is quantified by the coefficient of variation ( $CV$ ).

For the purpose of calculating power in population and abundance studies Gerrodette (1987) formulated six equations (Table 4.1) that define the relationship between  $r$ ,  $n$ ,  $\alpha$ ,  $CV$  and  $\beta$ . These equations can be used to calculate the value of any one of these parameters if the other four are known. However, certain assumptions must be fulfilled. It should be known whether the trend under consideration is linear or exponential to choose the right family of equations. In addition, the trend should be uniform over the whole study period. If a population was declining and then started to recover, these must be treated as two different trends. Using these equations several vital questions about the design of field study programme (such as how many samples are required? how precise should they be?) can be answered. A more frequently asked question is how precisely can a certain trend be detected by a particular programme? Solving for  $\beta$  provide the answer.

Link and Hatfield (1990) commented on the calculations suggested by Gerrodette (1987), and suggested that the t-distribution rather than the z-distribution should be used as the underlying model for estimating the power of the linear regression to detect a trend in population size. They showed that assuming the variance of the abundance estimate is normally distributed may cause overestimation of the power, especially for small sample size ( $n < 20$ ). They suggested that the t-distribution provides more appropriate values for the 97.5<sup>th</sup> percentile to be used in estimating  $\beta$ . When  $\alpha = 0.05$ , the t-distribution yields 97.5<sup>th</sup> percentiles of 3.182, 2.306 and 2.101 for  $n = 5, 10$  and 20 respectively, whereas the equivalent value for the z-distribution is 1.96 for all values of  $n$ . Also, the t-distribution is more correct, because it provides a better approximation of the distribution of the test statistic under the alternative hypothesis and it does not involve the assumption that the variance is known, which the z distribution does.

In this chapter, I have used the t-distribution as the underlying model with  $(n-2)$  degrees of freedom.

| Rate of change | Relation of A & CV                 | Equation  |
|----------------|------------------------------------|---|
| Linear         | $CV(A) \propto \frac{1}{\sqrt{A}}$ | $r^2 n(n-1)(n+1) \geq 12cv_1^2 (Z_{\alpha/2} + Z_{\beta})^2 \cdot \left[ 1 + \frac{r}{2}(n-1) \right]$  |
| Linear         | $CV(A) \propto \sqrt{A}$           | $r^2 n(n-1)(n+1) \geq 12cv_1^2 (Z_{\alpha/2} + Z_{\beta})^2 \cdot \left\{ 1 + r(n-1) \left[ 1 + \frac{r}{6}(2n-1) \right] \right\}$                               |
| Linear         | CV(A) is constant                  | $r^2 n(n-1)(n+1) \geq 12cv^2 (Z_{\alpha/2} + Z_{\beta})^2 \cdot \left\{ 1 + \frac{3r}{2}(n-1) \left[ 1 + \frac{r}{3}(n-1) + \frac{r^2}{6}n(n-1) \right] \right\}$ |
| Exponential    | $CV(A) \propto \frac{1}{\sqrt{A}}$ | $[\ln(1+r)]^2 n(n-1)(n+1) \geq 12(Z_{\alpha/2} + Z_{\beta})^2 \left\{ \frac{1}{n} \sum_{i=1}^n \ln \left[ \frac{cv_1^2}{(1+r)^{i-1}} + 1 \right] \right\}$        |
| Exponential    | $CV(A) \propto \sqrt{A}$           | $[\ln(1+r)]^2 n(n-1)(n+1) \geq 12(Z_{\alpha/2} + Z_{\beta})^2 \left\{ \frac{1}{n} \sum_{i=1}^n \ln [cv_1^2 (1+r)^{i-1} + 1] \right\}$                             |
| Exponential    | CV(A) is constant                  | $[\ln(1+r)]^2 n(n-1)(n+1) \geq 12(Z_{\alpha/2} + Z_{\beta})^2 [\ln(cv^2 + 1)]$  |

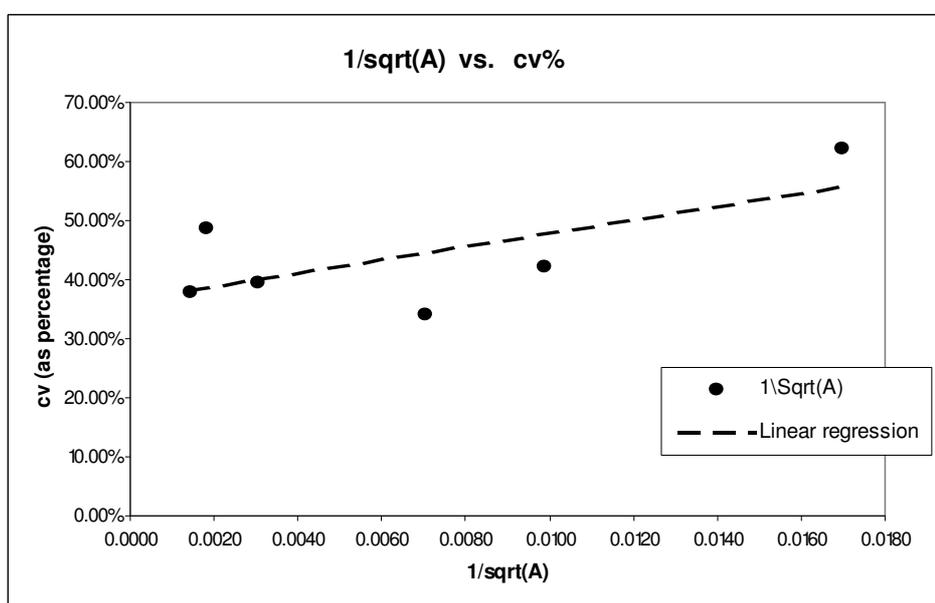
Table 4.1 Equation families used to calculate the power associated with detecting trends in population abundance (Gerrodette, 1987) Where:  $n$  is the number of surveys.  $r$  is the rate of change over the whole period of study in case of retrospective power or period required in case of prospective design.  $CV_1$  is the number of the coefficient of variation for the first survey or just  $CV$  when it is constant, as is the case of retrospective power or the required  $CV$  in case of prospective design.  $Z_{\alpha/2}$  are the critical values at the predefined type I error level to calculate  $Z_{\beta}$  in case of retrospective power. Or both are predefined in case of prospective design.

#### 4.4 Calculating the power of the current programme

To calculate the power of the current programme, the three assumptions required by Gerrodette's (1987) equations were investigated.

##### 4.4.1 Relation between abundance ( $A$ ) and $CV$

As the data were obtained using line transects the  $CV$  of  $A$  is expected to be proportional to the inverse of the square root of ( $A$ ) (Burnham *et. al.*, 1980). Figure 4.1 shows the relationship between  $CV$  and ( $1/\sqrt{A}$ ) for the six estimates of gazelle dung abundance for St Katherine's Protectorate and Nabaq Protected Area, it appears to be linear.



**Figure 4.1** Abundance estimates ( $1/\sqrt{A}$ ) and their associated  $CV$ s from surveys made in 1999, 2000 and 2001 in St. Katherine Protectorate and Nabaq Protected Area

##### 4.4.2 Presence and nature of trend

There are no historical estimates of the abundance of dorcas gazelles in the area of southern Sinai. Estimates are only available from 1999, 2000 and 2001 in the Qa'a (as I've mentioned before, you must be consistent in your spelling of place names. You used Qaa most of the time in Chapter 3) Plain and Nabaq area. Figure 4.2 shows the available time series for the two study areas. I considered both linear and exponential trends and calculated power using two different families of equations for each series of abundance estimates.

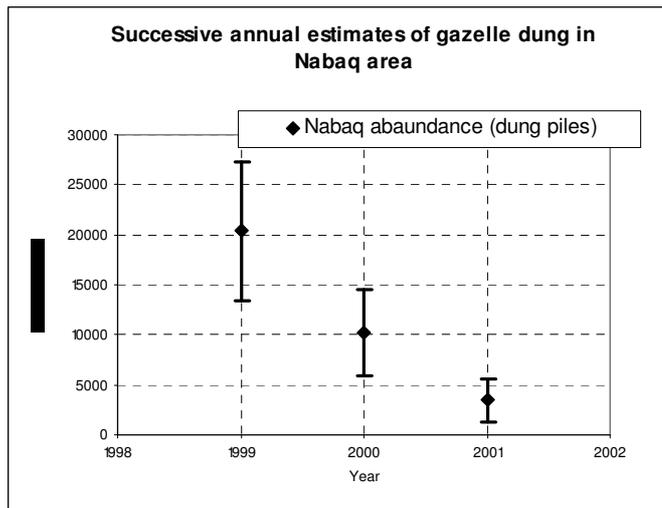
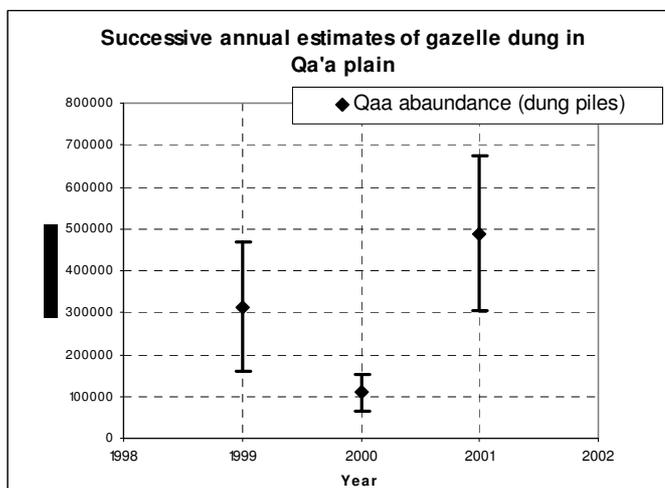


Fig (4.2) Available time series of estimates of gazelle dung abundance from:  
a) Nabaq protected area and  
b) Qa'a plain



#### 4.4.3- Power of programme in Qaa Plain

Over the period of 1999 to 2001 three annual surveys have been conducted in Qa'a plain in order to estimate the density of gazelle dung. The null hypothesis of no change in dung density could not be rejected for  $\alpha = 0.05$ . However, there are several questions to be answered in order to judge the effectiveness of the current monitoring programme for detecting changes in dung density. The most critical question is "How big a change in dung abundance is necessary before the current survey programme can detect it". Second, given the observed differences between years, how long will it take to detect a significant change? Finally, how can the power of the time series to detect change be enhanced?

According to Link and Hatfield (1990)  $r = b/(a+b)$  for the linear model, where  $b$  and  $a$  are the slope and intercept of the linear regression of the abundance on time. For the exponential model,  $r = \exp(b)-1$ , where  $b$  is the slope of the linear regression of  $\ln(\hat{A})$  on time. For Qa'a plain  $r$  was 0.41 for the linear model and 0.25 for the exponential model. The CV reported from the first survey is 0.4872 and  $n=3$ . The power of the time series to detect a change over a three-year period with  $\alpha=0.05$  and  $\alpha=0.1$ , is shown in Table 4.2.

**Table 4.2** Values of power ( $1-\beta$ ) for gazelle dung surveys in Qa'a plain over the period 1999-2001.

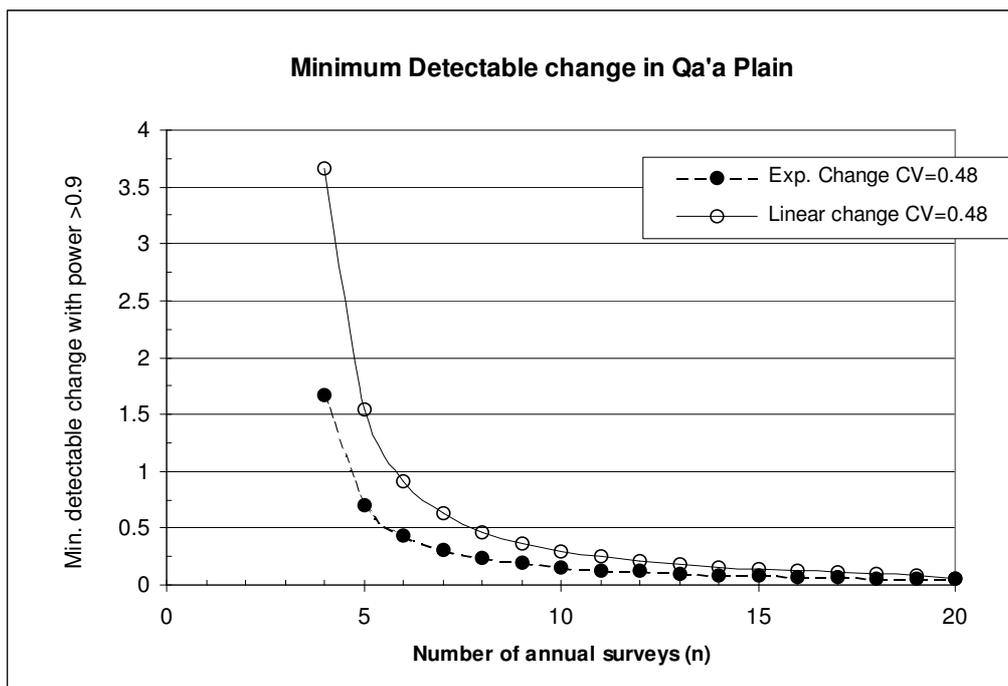
| Trend       | $t_{1,0.25}, t_{1,0.05}$ | $CV_1$ | $n$ | $r$  | Power at $\alpha=0.05$ | Power at $\alpha=0.1$ |
|-------------|--------------------------|--------|-----|------|------------------------|-----------------------|
| Linear      | 12.706, 6.314            | 0.4872 | 3   | 0.40 | 0.07                   | 0.14                  |
| Exponential | 12.706, 6.314            | 0.4872 | 3   | 0.25 | 0.06                   | 0.13                  |

A reliable programme should be able to detect trends of the desired level with a power of 0.9 or more. The minimum detectable change ( $r$ ) with power of 0.9 or more after 3 annual surveys is obtained by solving the equations for ( $r$ ). Values are shown in Table 4.3

**Table 4.3** minimum detectable change ( $r$ ) for gazelle dung surveys with power of 0.9 in Qa'a plain over the period 1999-2001.

| Trend       | $t_{1,0.25}, t_{1,0.05}$ | min. detectable $r$ at $\alpha=0.05$ | min. detectable $r$ at $\alpha=0.1$ |
|-------------|--------------------------|--------------------------------------|-------------------------------------|
| Linear      | 12.706, 6.314            | 51.61                                | 13.67                               |
| Exponential | 12.706, 6.314            | 117.30                               | 10.80                               |

The values from Tables 4.2 and 4.3 show that the existing time series has a very low ability to detect change. The power to detect trends does improve with time; a change of 150% can be detected after 5 years surveying and of 30% after 10 years in the case of a linear trend. The equivalent changes after 5 and 10 years with an exponential trend are 70% and 16% (Figure 4.3).



**Figure 4.3** Effect of increasing the number of annual surveys on the minimum detectable annual change with power >0.9 and CV=0.4872 for Qa'a Plain.

**4.4.4 Power of current programme in Nabaq area.**

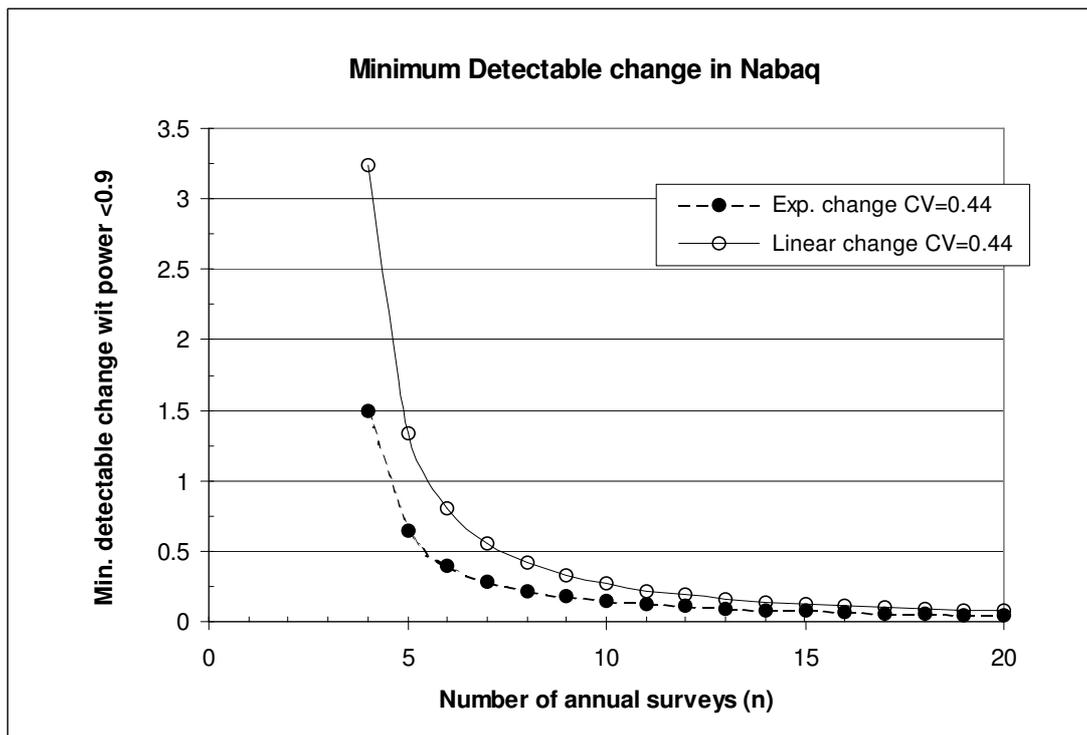
Over the period of 1999 to 2001, three annual surveys have been conducted in Nabaq area. Rates of change are  $r_{linear} = -0.230$  and  $r_{exp.} = -0.587$ . The CV reported from the first survey was 0.44. Table 4.4 shows the power of the programme to detect these changes over the three year period for  $\alpha=0.1$  and  $\alpha=0.05$ . The current time series is also of low statistical power and further surveying is clearly needed the minimum detectable  $r$  is extremely high after only three annual surveys.

**Table 4.4** Values of power ( $1-\beta$ ) for gazelle dung surveys in Nabaq protected area over the period 1999-2001.

| Trend       | $t_{1,0.25}, t_{1,0.05}$ | $CV_1$ | $n$ | $r$   | Power at $\alpha=0.05$ | Power at $\alpha=0.1$ |
|-------------|--------------------------|--------|-----|-------|------------------------|-----------------------|
| Linear      | 12.706, 6.314            | 0.44   | 3   | -0.23 | 0.05                   | 0.11                  |
| Exponential | 12.706, 6.314            | 0.44   | 3   | -0.57 | 0.07                   | 0.13                  |

**Table 4.5** minimum detectable change ( $r$ ) for gazelle dung surveys with power of 0.9 in Nabaq Protected area over the period 1999-2001.

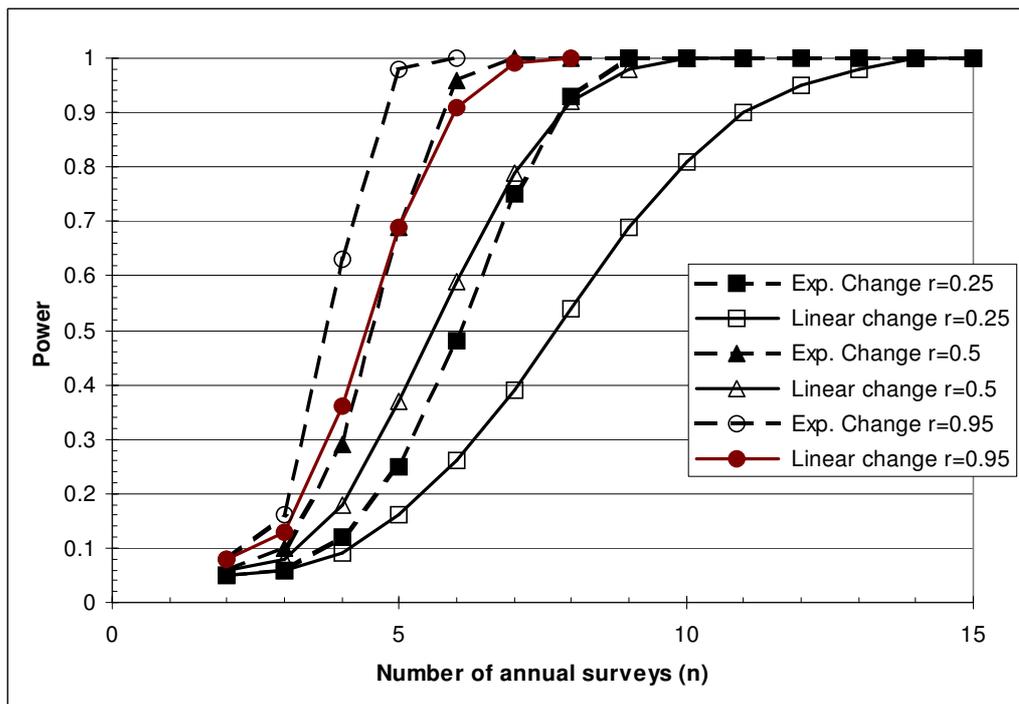
| Trend       | $t_{1,0.25}, t_{1,0.05}$ | min. detectable $r$ at $\alpha=0.05$ | min. detectable $r$ at $\alpha=0.1$ |
|-------------|--------------------------|--------------------------------------|-------------------------------------|
| Linear      | 12.706, 6.314            | 43.52                                | 11.62                               |
| Exponential | 12.706, 6.314            | 81.27                                | 8.26                                |



**Figure 4.4** Effect of increasing  $n$  on the minimum detectable annual change with power  $>0.9$  and  $CV=0.44$  in Nabaq Protected Area.

For the Nabaq Protected Area, Figure 4.4 shows that relatively small annual changes can be detected after 10 years of surveying. After about five annual surveys it is possible to detect a change of 40% if there is an exponential trends, and a change of about 80% after 6 years in the case of a linear trend.

To answer the second question: “given the observed differences between years, how long will it take to detect a particular change?”, equations should be solved for  $n$  using the observed values of  $CV_1$  and *specified values of  $r$  and  $\beta$* . Three arbitrary values for  $r$  (25%, 50% and 95%) were used to determine for the required time series to detect a particular overall change.

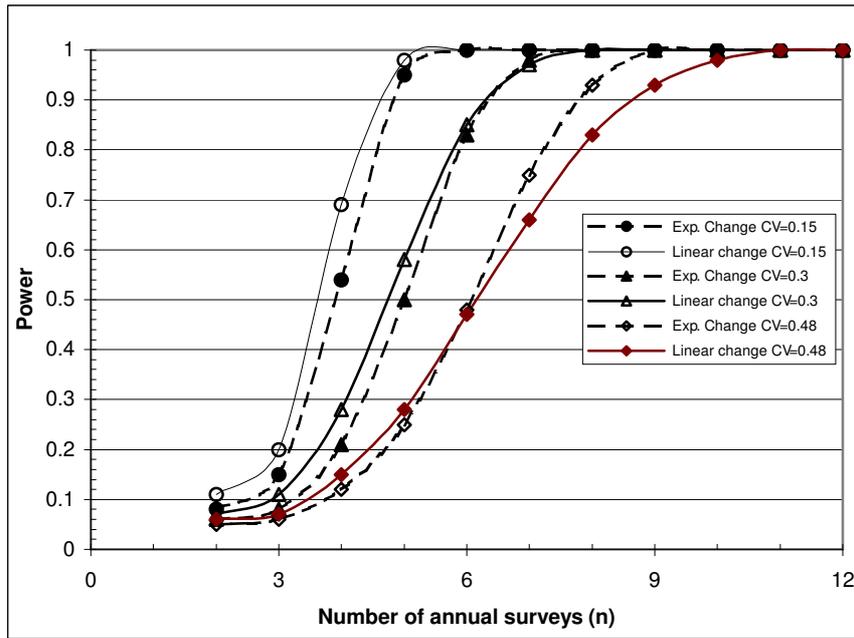


**Figure 4.5** Relationship between number of surveys and power of programme to detect trends of 25%, 50% and 95% assuming linear or exponential trends, and  $CV=0.48$  (Qa'a plain)

From Figure 4.5 it is seen that the programme requires 11 years to detect a 25% linear annual change, 8 years to detect a 50% change and 5 years to detect a 95% change in dropping density. If the underlying trend is exponential, the equivalent figures are 8, 6 and 4 years.

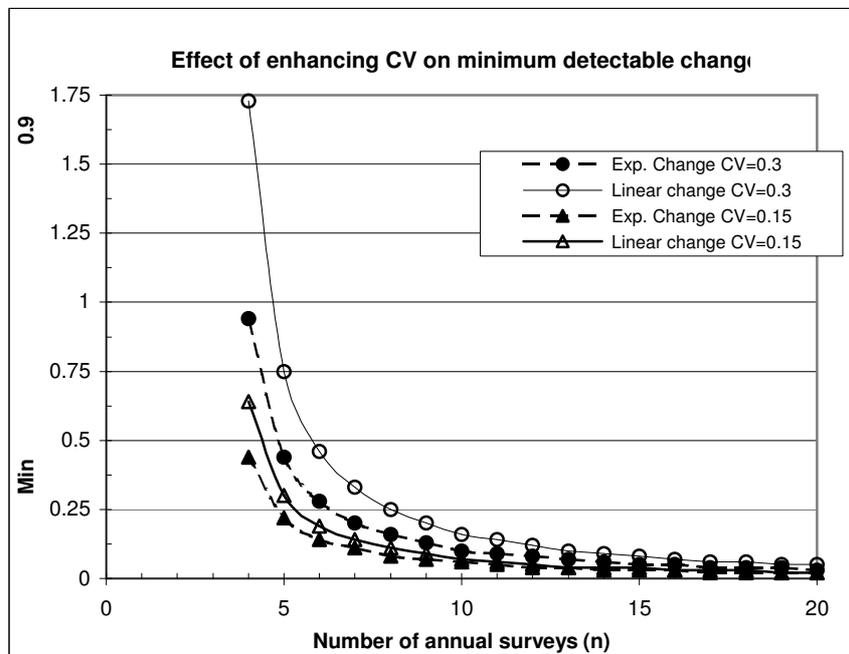
#### 4.4.5 Enhancing the statistical power of the current programme

In this section, I attempt to answer the question “how can the power of the time series to detect change be enhanced?” Obviously  $r$  cannot be altered and the effect of varying  $n$  has been discussed in the previous section. That leaves us with the  $CV$ , which is influenced by several factors, such as survey design, number of dropping encountered, strata homogeneity and the experience of the observers. The power of the programme could be drastically improved if the  $CV$  could be reduced in some way. For example, in Qa'a plain if the  $CV$  of the abundance estimates could be reduced to 30%, a significant linear or exponential trend could be detected after 7 years rather than 8-9 years with the current  $CV$  of 48%. A further reduction of the  $CV$  to 15% would reduce the detection interval to 5 years (Figure 4.6)



**Figure 4.6** Effect of reducing the CV of A on the power of the programme in Qa'a plain under linear or exponential trends.

There are similar effects on the) the minimum detectable change. If CV is reduced to 30%, changes as small as 44% with an exponentially tend or 75% with a linear trend can be detected after 5 years (Figure 4.7)



**Figure 4.7** Effect of reducing the CV ( $\hat{A}$ ) when there is a linear change of  $r = 0.405$  or an exponential change of  $r = 0.249$

### **4.5 Discussion**

The current monitoring programme has low power to detect changes over a small period of time because of the relatively low precision associated with the estimates of dropping density. Nevertheless, the minimum change that can be detected improves as the number of annual surveys is increased.

Decreasing the coefficient of variation of the estimates could substantially enhance the power to detect changes in population size. It may be possible to do this by re-stratifying the study region (Chapter 3), although this would result in the loss of the currently estimates. However, due to the fragmented habitat and the food resources available for gazelles being in scattered patches any stratification design will still show high variance, thus the CV is unlikely to be enhanced to reach the 30% or 15% levels. Enhancing the CV to 30% is expected to yield in detecting change after 7 years with starting from scratch while the current value of CV is expected to yield in the same result after 8 or 9 years but with the advantage of 3 years of data is already available. So carrying on with the same design is recommended as a trade-off over re-stratifying the study region in Qa'a plain.

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*Chapter 5***Modelling Spatial Variation**

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**5.1 Introduction**

Wildlife surveys often involve sampling the study area. As a result, there is not a comprehensive coverage of the study area. Sample size and, hence coverage is restricted by variety of factors. These factors may be natural, like terrain, which may render it easy to access some areas and very hard to get to other areas within the study region. The species under investigation might be present for only a short season each year, or might restrict its activity to certain times of the day or night. Other factors, such as budget, logistic resources and time allowed for the survey, could also constrain survey coverage. In addition, the survey design and methodology may also affect coverage. Conventional density estimation techniques generally rely on design-based sampling strategies. Estimates from these design-based surveys provide information on large-scale variations in density over the study area. A typical scale would be the geographic divisions used to stratify the sampling scheme. These strata must be large enough to ensure high number of observation to facilitate analysis within the stratum, a constraint that usually decreases the level of resolution.

Several methods have been developed to obtain finer resolution information on spatial variation in abundance or density from such surveys. Best and Butterworth (1980) used contouring to investigate variations in the density of minke whales in the Antarctic with respect to the location of the ice edge. The method involved drawing contours by hand around areas of similar school density. This method had many disadvantages (de la Mare and Cooke 1982), and does not provide estimates of variance. In a subsequent study Butterworth and Best (1982) used another geostatistical technique, universal Kriging. This method assumes that a data point is a random function that can be partitioned into two components: a linear combination of known functions representing the expected values of the parameter under investigation; and a random process representing the spatial correlation, described by a semi-variogram. It involves averaging observations from several points to produce one point representative of the site. This clouds the inherent structure of the data, and thus spatial correlation cannot be estimated with confidence. The method was abandoned for further investigation.

More recently, methods have been developed in which density is considered as a response variable whose variation can be explained using information on environmental factors that might

be expected to shape the way animals disperse within the study area. For example, Osborne and Tigar (1992) used logistic regression to model bird distribution in Lesotho. Presence/absence data for the species of interest were collected within a grid, along with information on the values of several habitat variables. Buckland and Elston (1993) used a similar approach to model the probability of occurrence of red deer (*Cervus elaphus*) in grid cells in northeast Scotland. Using the same data set, Augstin *et al.* (1996a and 1996b) enhanced the logistic regression model by introducing an autocovariate term.

Borchers *et al.* (1997) used a two-stage generalised additive model (GAM) to study the distribution of horse mackerel (*Trachurus trachurus*) eggs in the northeast Atlantic. First they used a logistic regression to model the presence/absence of eggs from sample locations, and then they fitted a GAM with a gamma error distribution to the egg number in those cells from which eggs were reported. Headly (2000) developed an approach using GAMs to analyse data collected using line transect surveys. This work, and that of Wood (2000, 2001), provided the basis for the spatial modelling of dung density described in the rest of this chapter.

## **5.2 Spatial modelling of gazelle density**

Generalized additive modelling was selected as the method to model variations in gazelle dung density throughout the study region. Data were analysed using the add-in package **mgcv** developed by Wood (2001) for the free software package **R** (<http://www.r-project.org/>). The GCV scores increased with increasing number of knots that means more complex models are not performing any better from the initial model with 10 knots. In addition, the expected degrees of freedom (edf) has also showed an increasing pattern with more complex models. Thus, the initial model was adopted for modelling the heterogeneity in spatial distribution of gazelle dung.

Wood (2001) has provided the following description of the package “**mgcv** provides tools for GAMs and other generalized regressions. GAMs are presented in **mgcv** as penalized generalized linear models (GLMS) with smoothing parameters (equivalent degrees of freedom) chosen by Generalized Cross-Validation (GCV). Each smooth term of a GAM is represented using an appropriate set of basis functions and has an associated penalty measuring its wiggleness (the weight given to each penalty in the penalized likelihood as determined by its smoothing parameter). Models are fitted with the usual iteratively re-weighted least squares scheme for GLMs, except that, at each iteration, the conventional value is replaced by a penalized value in which the smoothing parameters are chosen by GCV”.

Wood (2000) describes the way that the GCV selects for good fit of GAM as a method of Iterative model fitting with one piece of data is omitted at each iteration. Then the (squared)

difference between the missing datum and the model prediction of the missing datum. Repeat this process for each datum, and calculate the mean square difference between models (fitted to all data but one missing datum) and missing data. This mean square difference is an objective, which should be minimized to find the optimal smoothing parameters. The idea is that a model that is too smooth will not closely match the data to which it has been fitted and will tend to do no better on missing data. Conversely, a model that is over-flexible will fit every bump and wiggle of the data, including the noise component, and will thus tend to do rather poorly at predicting missing data. Models of intermediate complexity will do better.

### 5.2.1 Model formulation

There is a need to deploy the ecological experience from previous observations in the study region to identify what seems to be an affecting factor that could have significant role in shaping the spatial distribution of dorcas gazelle through the study area.

Human presence could be an essential factor and probably gazelles are avoiding people and are seeking maximum available shelter from any human impacts. Although direct human presence is scant in the area, there are few scattered points of temporal human presence such as the temporary boulder collecting sites and some temporal grazing camps. Boulder collection sites are kept away to the northern part of the Qa'a plain. Grazing camps could be easily drawn out because of being out of use for the last 6 consecutive years due to drought enduring since 1997 and up till the time being, hence no vegetation is available for feasible livestock grazing. Vehicle tracks and trails are the major prominent signs of human presence in the area. Vehicles are seeking the most favourable lands to cruise. The plains around the mountains are either harsh for the tyres or covered with boulder fields that make access hard or impossible. Observations showed that gazelles are relatively more abundant in these terrains. Unfortunately the scale used to assess the type of terrain in the applied methodology is categorical and not linear which makes it not suitable to be used as a parameter in the GAM. A compromise is sought in using distance of the transect centre point from the mountain edge as a representative of the terrain type since it is more boulders to gravel around mountains than it is away from them. Distance from mountain is decided as one of the parameters to incorporate into the predictive model

Bedouins in south Sinai do not undertake organized grazing for their camels rather they leave their camels to wander freely in the deserts. As a consequence camels are freely ranging on their own like any other wild herbivore. This would mean that mutual interaction between the two

herbivore species (camels & gazelles) occupying the same landscape and seeking a common food resource will result into some spatial partition of the landscape between the two species. Therefore, presence of camels is very likely to impact the distribution of gazelles. Any attempt to account for evaluating or predicting the spatial distribution of gazelles should not overlook the presence and distribution of camels as free ranging animals. Camel dung encounter rate was adopted as a measure for camel presence and the observed values of this parameter were selected to be incorporated into the predictive model intended as an explanatory variable.

In addition to the aforementioned parameters that are elucidated from direct ecological or biological contexts observed to prevail in the study area, there are additional parameters to consider. The observed values of encounter rate of gazelle droppings over the survey area (figure 3.9) suggest that there is a pattern of the density to be higher in the southern part of the study area compared to more northern latitude values. Also as a result of the above described effect of the mountain edge there is a tendency for higher density on the east of the study area compared to western parts. Thus the model needs to include latitude and longitude to account for this spatial variability and also to describe as a spatial model.

Initially data exploration was done to investigate models of a single variable as the explanatory variable and different combinations of variables mentioned above. All models used during data exploration were done using 10 knots, gaussian family and identity link function. To start with modelling was done using camel dropping encounter rate and distance from the mountain as the explanatory variable independently and simultaneously respectively. Compared to the distance analysis-based estimate, the results were not satisfactory at all with a density estimate of 351.49 per Km<sup>2</sup>, C.V.=63.11 for camel rate encounter, and 1675.85 per Km<sup>2</sup>, C.V.=21.12 for camel rate encounter and distance from mountains simultaneously. Following, the distance from the mountain was doing even worse giving an estimate of 2058.87, C.V.=5.11.

Next Step is to test models of different explanatory variables in combination with latitude and longitude. First combination tested was to use camel encounter rate, latitude and longitude in one model. Second, a combination of distance to mountains, latitude and longitude was ran. Again model performance was not satisfactory in comparison to the distance analysis-based estimate of gazelle droppings density. A density estimate of 82.32 per Km<sup>2</sup>, C.V.=61.77 for camel rate, lat., and longitude model and 371.35 per Km<sup>2</sup>, C.V.=88.73 for distance to the mountain, lat. And long model. Although the latter model (distance from mountain, Lat. And Long) produced the nearest estimate of density compared to the distance sampling estimate (222.8 dropp./Km<sup>2</sup>) it contained

high amount of imprecision around it where coefficient of variation reached up to 88%. Additionally a model using only latitude and longitude as explanatory variables was also run. Following, the distance from the mountain was doing even worse giving an estimate of 2058.87, C.V.=5.11. Finally, a combination of latitude and longitude was run. Although the resulting prediction had very low imprecision of CV=5.58, the point estimate was about twice the observed density where it was 457.05 dropp./Km<sup>2</sup>. Listing of parameter estimates of all tested models are given in table (5.1) . Figure (5.1) shows the frequency distribution of predictions for the same models. Figure (5.2) shows the spatial display of the prediction of various exploratory models examined in the process of data exploration.

Table (5.1) comparison of estimates of gazelle droppings density (pile/Km<sup>2</sup>) from a two different models using GAM prediction over Qa'a plain.

| X variable                                 | Estimates |       |         |         |
|--|-----------|-------|---------|---------|
|  | <i>b</i>  | CV%   | LL. CI. | UL. CI. |
| Camel rate                                 | 351.49    | 63.11 | 0       | 785.59  |
| Distance to mountains                      | 2058.87   | 5.11  | 1852.62 | 2265.13 |
| Camel rate & Distance to mountains         | 1675.85   | 21.12 | 981.69  | 2369.73 |
| Latitude & Longitude                       | 457.05    | 5.58  | 406.99  | 507.09  |
| Camel rate, Latitude & Longitude           | 82.32     | 61.77 | 0       | 181.97  |
| Distance to mountain, Latitude & Longitude | 371.35    | 88.73 | 0       | 1017.16 |

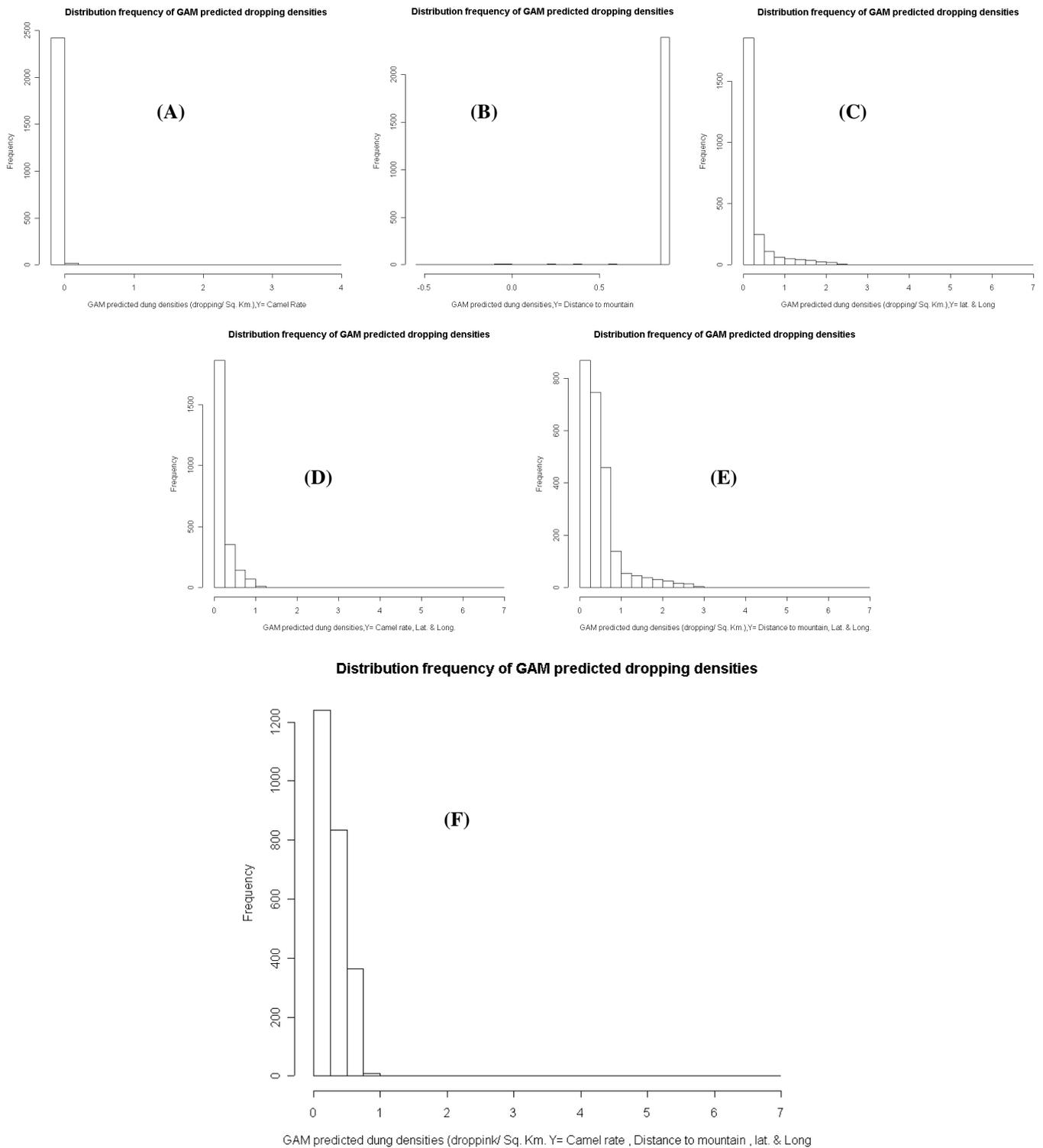


Fig (5.1) frequency distribution gazelle droppings density predictions of various models used through data exploration process.

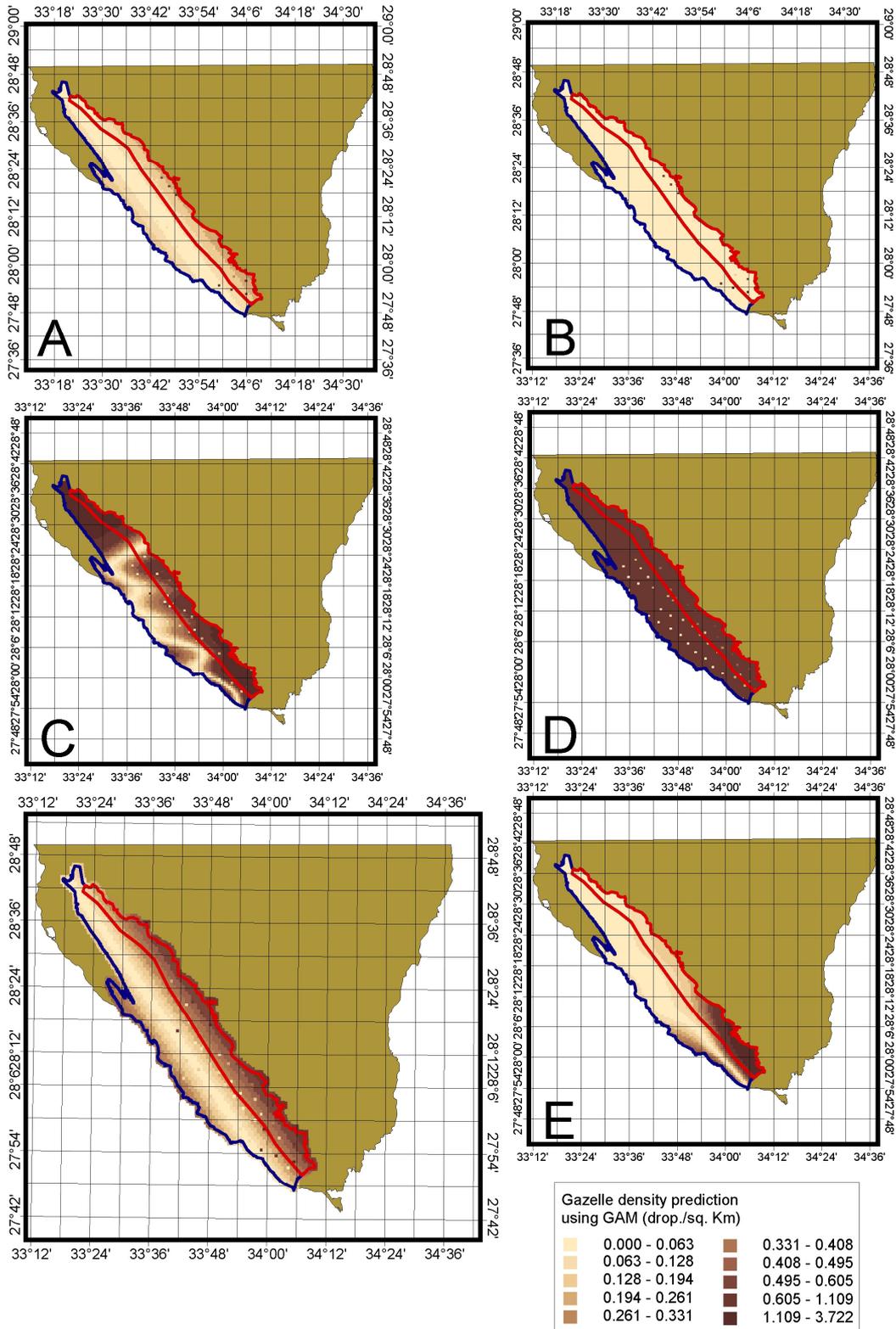
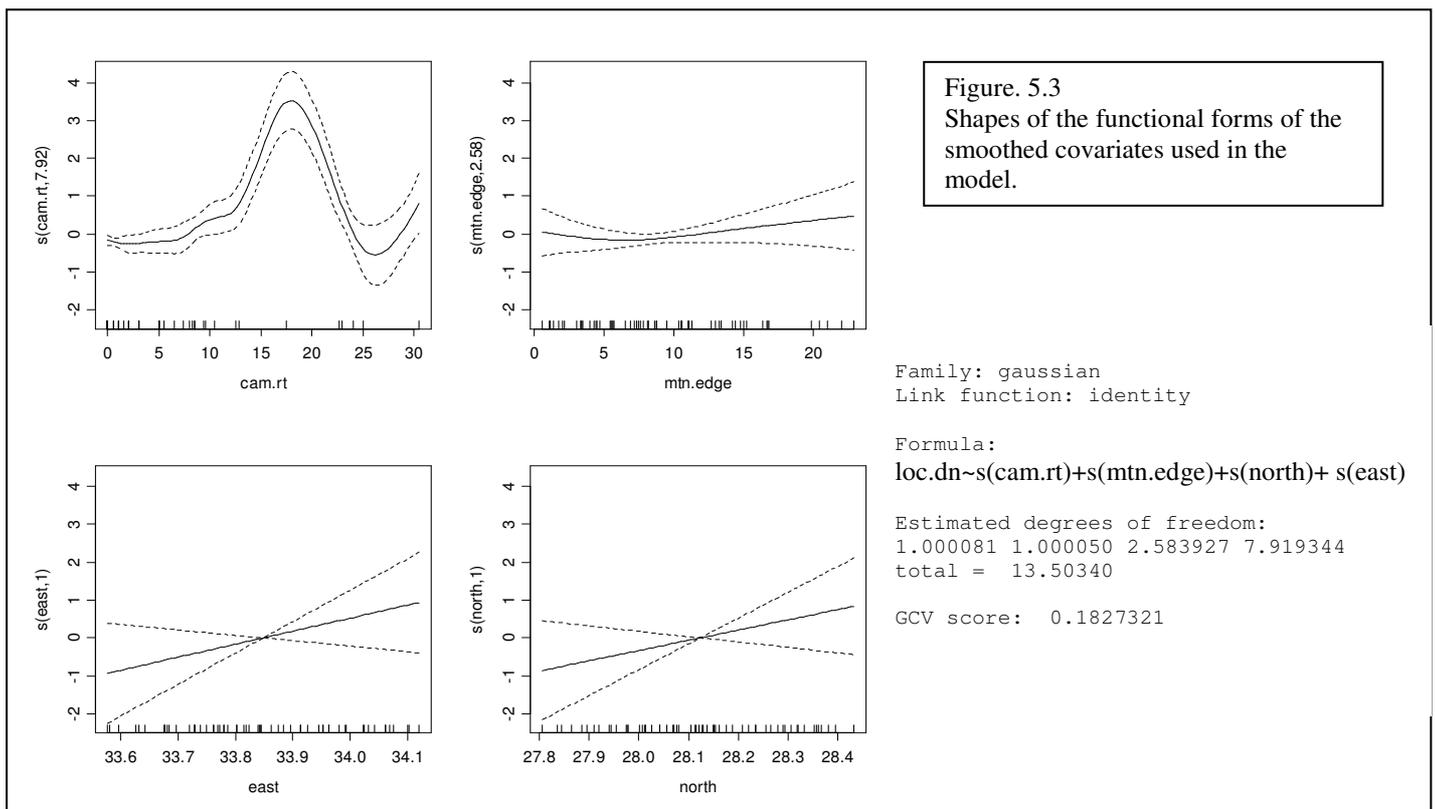


Fig (5.2 ) maps showing the results of the five possible predictive model based on a) Camel rate, lat. and Long, b) camel rate only, c) distance to mountain, long, and lat., d) distance to mountain only and e) latitude and longitude.

From the above discussion, four independent variables were selected for predicting the values of the response variable: camel dung encounter rate, distance from transect mid-point to the mountain edge, latitude of the transect mid-point, and longitude of the transect mid-point

Figure 5.3 shows the results of fitting this GAM to the data. To determine whether a more complex function was required, additional knots were added to the model. By default, the `gam()` function in `mgcv` assigns 10 knots to a function. An exploratory trial to fit more complex models with 12 and 13 knots was done to test for better fitting. Results for 11 and 12 knots testing are shown in Fig (5.4)



For predicting spatial heterogeneity in gazelle dung density in all over Qa'a plain, a 1.0 km grid was overlaid on the study area. The grid was created using ArcView planimetric script applied over a set of polygons digitised from a 1:250,000 map in ETM (Egyptian Transverse Mercator, Annex I) projection and Old Egyptian spheroid (blue belt) (Helmert-1907). Figure 5.5 shows the predicted values of gazelle dung density as a raster map overlaid on the study area. Gazelle dung is most likely to be encountered in the south eastern corner of the study area, with density declining towards the north and northwest.

**b) 12 Knots df=11**

```
Family: gaussian
Link function: identity

Formula:
loc.dn ~ s(cam.rt, 12) + s(mtn.edge,
12) + s(east, 12) + s(north ,12)

Estimated degrees of freedom:
1.010365 1.010861 1.775922 7.896202
total = 12.69335

GCV score: 0.1994040
```

**d) 13 Knots df=12**

```
Family: gaussian
Link function: identity

Formula:
loc.dn ~ s(cam.rt, 13) + s(mtn.edge,
13) + s(east, 13) + s(north , 13)

Estimated degrees of freedom:
1.098304 1.176852 1.645044 7.900505
total = 12.82071

GCV score: 0.2143670
```

Figure 5.4 Results of investigating different number of knots in fitting GAM for predicting dung density allover study area

**5.2.2 Model Validation**

Unfortunately no formal method is available to evaluate the goodness of fit of GAM other than GCV. As mentioned earlier, goodness of fit is indicated by a low GCV score and low expected degrees of freedom. There are two other approaches that can be used to validate the model: graphical analysis (of the fitted values vs. observed values, and of residuals), and resampling. If we have a good model, the residuals should appear as uncorrelated scatter when plotted.

Figure 5.6 shows the expected linear relationship between observed and predicted values, and no obvious pattern in the residuals. However, the linear relationship between observed and expected values is largely driven by a single high value. The cluster of points around the bottom left corner is a consequence of the fact that the encounter rate in most cells is predicted to be zero, the single high value is a consequence of an with 46 dung piles on transect (8).

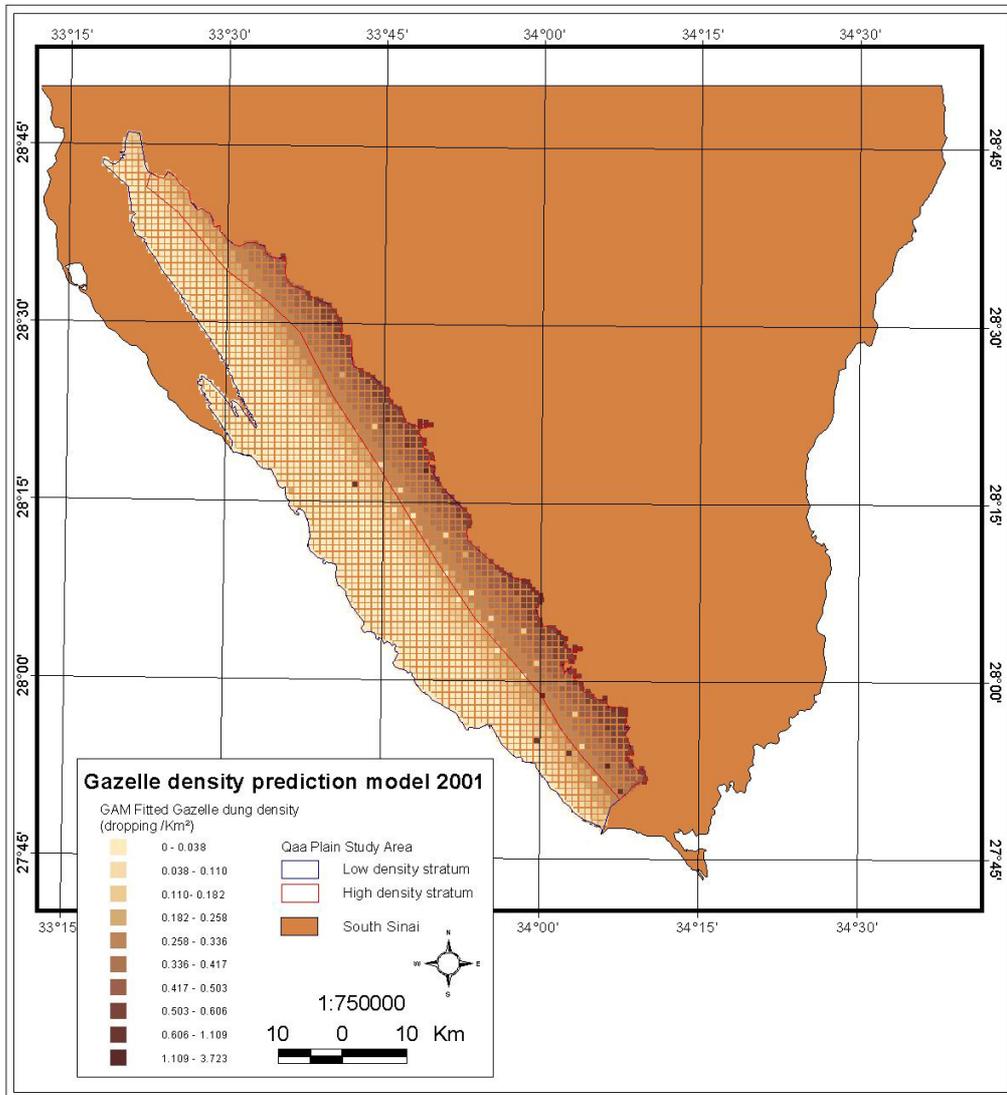


Figure. 5.3 Predicted density of dorcas gazelle dung droppings in the Qa’a plain study area as predicted from a model based on Gaussian smoothing splines of distance from mountain edge, presence of camel dung, latitude and longitude.

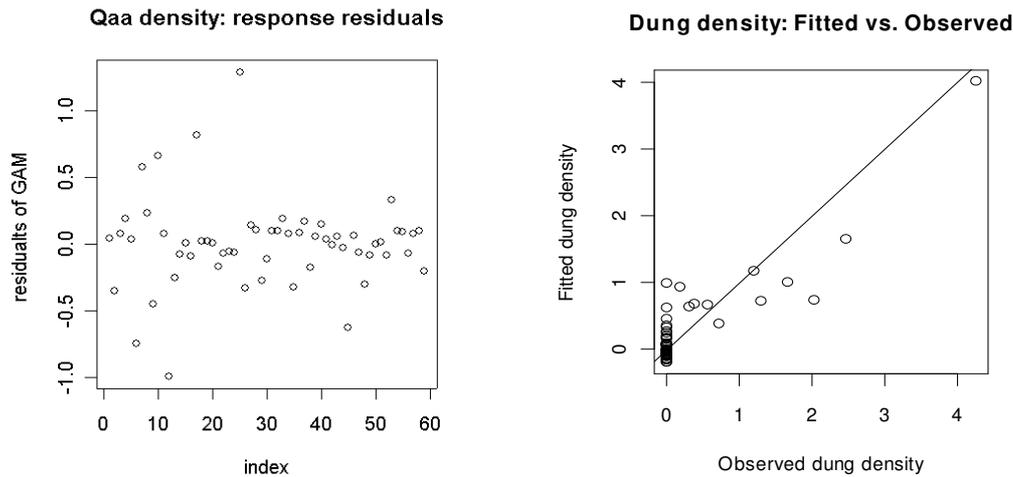


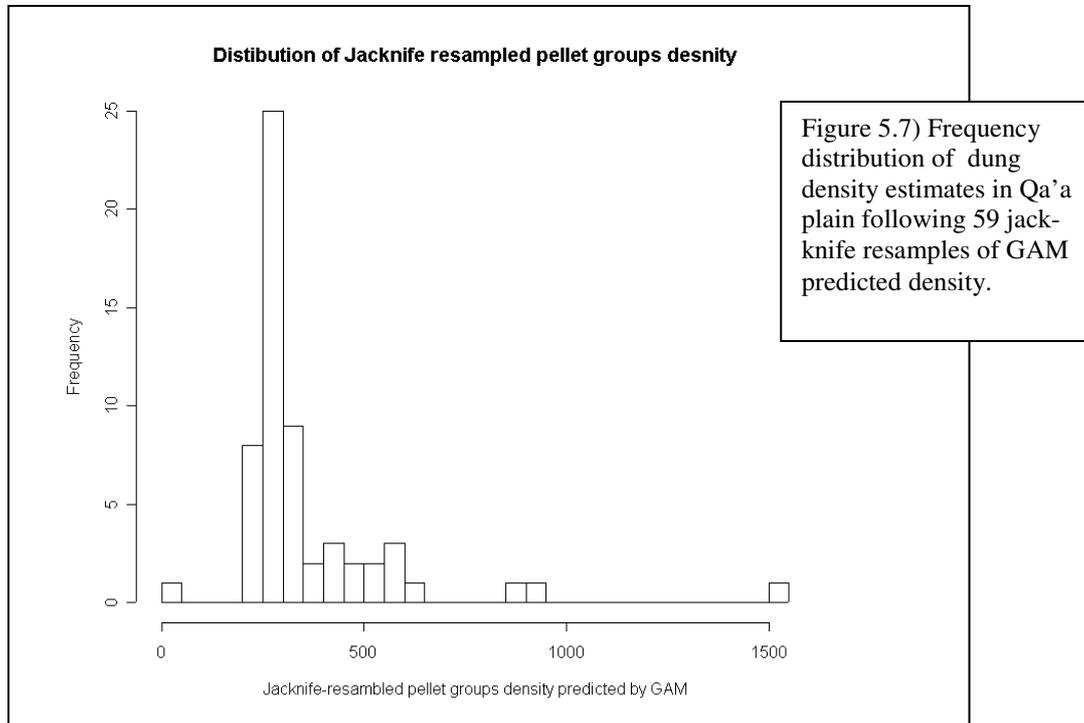
Figure 5.6 Graphical validation of GAM used to predict variations in gazelle dung density.

Further the validity of the model is again tested through resampling or bootstrapping. Jack-knife resampling was used to produce point estimate of dung density from the predicted model which could be compared with the estimates produced from distance analysis of the observed data. Jack-knifing is usually applied to a set of  $n$  observations by systematically omitting one observation at a time to create  $n$  samples of sizes of  $n-1$ . In our dataset there are 59 transects (sampling units). The jack-knife samples were obtained by systematically removing row one transect, fitting the model and using the predicted model to predict dung density for the grid cells. Summing the values of predicted density all over the grid cells will give an estimate of the predicted density at  $\hat{D}^{(-t)}$ ,  $t=1\dots59$ . Where the superscript  $(-t)$  means the density estimate is calculated from the  $t^{\text{th}}$  Jack-knife sample (i.e. with the  $t^{\text{th}}$  transect omitted). The mean of these estimates is considered as the density estimate of the spatial model. Coefficient of variation and confidence intervals were calculated for the new density estimate. Model estimates are subscripted as  $(j)$  to distinguish them from distance analysis estimates. The density estimates from the jack-knife resampling were divided by 6.25, because they are based on the predicted number of dung piles for 2.5km x 2.5km grid cells. Table 5.2 compares the point estimates from the distance analysis with those from the Jack-knife resampling.

Table (5.2) Comparison of estimates of gazelle dung (pile/Km<sup>2</sup>) density from a conventional Distance analysis and the spatial modelling approach. Subscript  $(j)$  denotes values estimated using Jack-knife resampling.

|            | Distance analysis |       |         |         | Spatial Model |                   |                      |                      |
|------------|-------------------|-------|---------|---------|---------------|-------------------|----------------------|----------------------|
|            | $\hat{D}$         | CV%   | LL. CI. | UL. CI. | $\hat{D}_j$   | CV <sub>j</sub> % | LL. CI. <sub>j</sub> | UL. CI. <sub>j</sub> |
| Qa'a Plain | 222.51            | 37.91 | 105.38  | 469.83  | 366.65        | 8.98              | 300.75               | 432.56               |

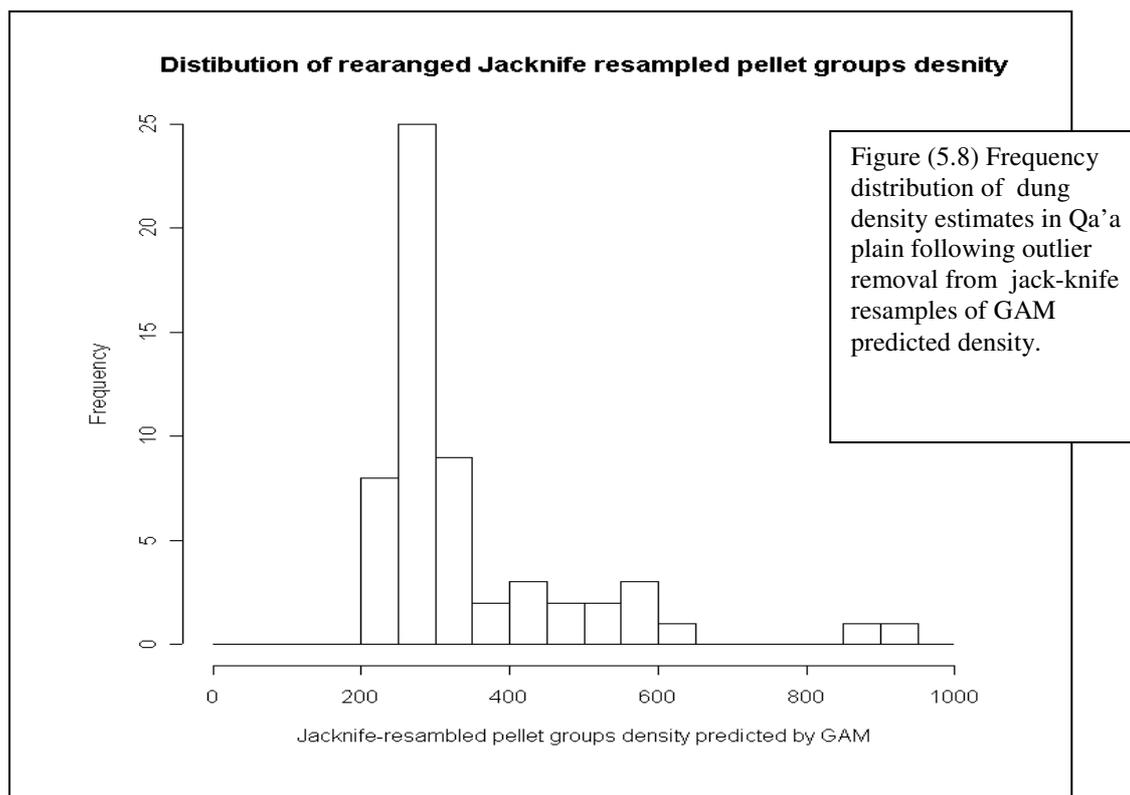
The spatial model seems to overestimate the gazelle density compared to the observed density estimate. Density estimate obtained by the spatial model seems to have higher imprecision around it which manifested by the wider confidence interval.



Looking at the frequency distribution of the dung density estimate obtained through jack-knife resampling Fig.(5.8) shows that the distribution is right skewed with only one data point at the far left interval and one at the right. If these points are considered as outliers and removed from the distribution the precision of the model based is enhanced. Table 5.3 lists the model based dung density estimate and its associated 95% confidence interval following outliers removal from the frequency distribution.

Table(5.3) estimates of gazelle dung density and 95% confidence interval from the spatial modelling approach. Subscript (*j-rearranged*) denotes values estimated using the jack-knife with outlier removal.

| Spatial Model ( with outliers removed) |                                    |  |  |
|--|------------------------------------|--|--|
| $\hat{D}_{j-rearranged}$               | CV% <sub><i>j-rearranged</i></sub> | LL. CI. <sub><i>j-rearranged</i></sub> | UL. CI. <sub><i>j-rearranged</i></sub> |
| 340.29                                 | 7.39                               | 289.92                                 | 392.62                                 |



### **5.3 Conclusions**

Although the use of generalized additive models is emerging as an established method for modelling the spatial distribution of wildlife, they are still not widely used. The use of model-based, rather than sample-based, estimates can be useful in situations where sampling coverage of the area under investigation is representative but not comprehensive. In this example, the model-based approach provided a good estimate of spatial variation in the response variable (gazelle dung density), but with a rather high degree of uncertainty. This could have been reduced if larger sample sizes had been available. Jack-knife resampling is also more effective when a large number of samples is available.

The choice of explanatory variable couldn't be emphasised more where bad combination of selected variable could highly deteriorate the resulting prediction as shown during data exploration. Thus it is highly recommended to use both intuitive information from the biological and ecological context surrounding the species under investigation along with some preliminary model fitting prior to the final selection of explanatory variables. Although, incorporating more explanatory variables may be a tempting to increase the model efficiency, number of explanatory variables should be controlled to minimal for the sake of model parsimony.

Gazelle density is thought to be strongly affected by other environmental variables, such as the availability and distribution of food plant species. The distribution of these plant species may also be affected by distance from the mountain edge, which, in this case, was probably acting as a surrogate variable. The relationship between vegetation coverage and species richness at the mid-point of each transect and the spatial explanatory variables used in this analysis will be investigated at a later date.

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*Chapter 6***Conclusion & Recommendation**

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**6.1 Introduction**

Dorcas gazelle (*Gazella dorcas*) is poorly studied in Egypt, but it is subject to many threats throughout its range. Recently, with the general increase of conservation efforts and awareness in Egypt, the species is being considered by the conservation authorities as a potential flagship species, to raise public awareness and accelerate the process of protecting and conserving the national natural heritage. Also, there was a need to have an example of how a monitoring study could contribute to conservation and justify governmental spending. It was believed that gazelles are a sufficiently charismatic and culturally appealing species for this purpose. The present study focused on the small proportion of the global population that is resident in Egypt. Several attempts had been made before the current study to develop a monitoring program. The work described in this thesis is an attempt to formulate and test a monitoring programme that is applicable in most habitats where the species occurs, and that can be conducted with the manpower and logistic capabilities that are available to the National Parks of Egypt.

**6.2 Current state of knowledge:**

There are very few publications on the ecology and status of dorcas gazelles (Groves, and Harrison 1967, Ghobrial 1970a, Ghobrial 1970b, Dittrich, L., 1972, Ghobrial 1974, Mendelsohn 1974, Baharav, 1980, 1981, 1982 & 1983, Ferguson 1981, Furley 1986, Grettenberger 1987, Saleh 1987, Lawes and Nanni 1993, Loggers, Ward and Slatz 1994). Most of these studies were concerned with physiological and taxonomic aspects of the species. Only the studies of Loggers (1991, 1992) in Morocco and Lawes and Nanni (1993) in the Negev desert provided any information on the size of dorcas gazelle populations, and no studies provided a time series of population assessments. Only Saleh (1987) provide any information on the Egyptian population of dorcas gazelle. The current work represents an essential addition to our knowledge of this species since it describes a monitoring programme that is easily applicable in a wide variety of habitats and could provide a time series of estimates of an index of abundance.

The current work also provides a preliminary estimate for the rate at which gazelle droppings decay. This is an essential parameter for converting indices of gazelle abundance based on dropping density into estimates of abundance.

### **6.3 Recommendation for future surveys**

In future surveys every effort should be made to maintain a fairly constant timing of the survey to be carried on. That's to say constant annual schedule is of considerable significance for the sake of obtaining comparable results. Since decay rate is of such importance, constant timing of survey sessions will decrease sources of bias arising from variable amount of gazelle dung in irregular intervals between successive surveys while constant interval between surveys would ensure that the change in the dung density and abundance is of direct relation to changes in animal population more than any other factor.

An other categorization scheme is required for the terrain type and plant cover to ensure well defined categories for covariates influencing the observer detection function since the current one is proved to result in very similar detection function to that interpreted using no covariates.

Observers should be instructed to maintain constant level of alertness especially in the low density areas. If new observers are to join the survey team in following years some care should be given to training new observers in true survey conditions in both low and high density strata to avoid the observer dependant sources of bias shown in section 3.1.1

### **6.4 Recommendation for management**

A monitoring programme in the study area that was based on dropping surveys would require 11 years of data to detect a 25% linear annual increase, 8 years to detect a 50% change and 5 years to detect a 95% increase in dropping density. If the underlying trend is exponential, the equivalent figures are 8, 6 and 4 years. The main recommendation is that monitoring should be part of a long- term program that was proved to yield a reliable estimates with enhanced power through time. The successive estimates dun density & of abundance as shown in figure (4.2) provided some evidence that the population had recovered from its previous decline.

The main gazelle population of South Sinai, in the Qa'a plain, is outside the borders of any of natural reserves. It would therefore be advisable to provide formal protection for this population by declaring the core habitat in the south Qa'a plain as a wildlife sanctuary.

Also results showed that there is an increasing density of gazelle droppings in Qa'a plain where it is decreasing in Nabaq Protected Area. First, Management should make it clear that a primary conservation priority is to conserve and maintain the currently available gazelle habitat in Qa'a plain ( the southern-eastern corner) and protect it against invasive activities which may lead to further habitat destruction. Although gazelles are not occurring in the north of Qa'a plain the areas adjacent to the mountains should be given an equivalent conservation priority since these are shown as favourable habitats by the predictive model. Conserving those habitats is essential for the future spread of gazelles as a result of the future expected recovery and population size increase. Second, an investigation should be pursued to define the causes for the decline observed in Nabaq Protected Area.

There is an increasing calls for starting captive breeding programs for endangered or declining species in Egypt. It is clearly known that these programs require high input of funds and technical manpower in order to get satisfactory results. Although this is not a direct outcome of the current study, there is an observed increasing pattern of gazelle abundance and density indices in Qa'a plain. This shows that the *in-situ* conservation of a still-occurring species (even in low densities) like the dorcas gazelle could be much more cost effective rather than the *ex-situ* conservation given the proper time period. Therefore, it is recommended to exclude the dorcas gazelle from the list of candidate species nominated for captive breeding programs in Egypt and to conduct careful surveys of the other species on the list before initiating any attempts.

#### **6.4 Further Extension of work.**

In south Sinai, gazelles are found in two centres: a larger, western e population in Qa'a plain, and a smaller, eastern population in the Nabaq protected area. There are some suggestions from previous workers (Wacher, *personal. communication*) that the two populations are isolated from each other, ant that there is a risk of inbreeding in Nabaq population. The genetic variability in both populations should be assessed to

determine if translocation between the two populations is required. Current advances in molecular genetics have made it possible to extract DNA from faecal samples (Goossens 2000 a & 2000b). Dorcas gazelle faecal samples are quite abundant and easy to obtain in the two regions.

The current study has provided an estimate for gazelle droppings decay rate over a year of time. However, There is a need to apply a second phase of the study where individual fresh dung is marked and followed up through time to account for when dung is departing from one category to another through the six categories noted in section 2.3.2.the relative decay rate of each category, and to calculate the probability of transition between the six categories in interval between visits.

Nothing is known about the feeding ecology of dorcas gazelle in Egypt. Microhistological methods for the analysis of herbivores faeces (Voth and Black 1973, Stewart and Stewart 1967 and Gaylard and Kerley 1997) would provide an indication of the plant species consumed by dorcas gazelles in Sinai. Feeding studies with captive animals would be required to calibrate these methods and to study food preference. The results of such studies could be used to identify favourable habitats for the species.

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**Annex I: Egyptian Transverse Mercator**

The national grid systems of Egypt are based on a transverse Mercator projection and are composed of 3 different zones. Each of the 3 zones has an independent coordinate system. These zones are termed as belts. The most eastern is the blue belt starting at longitude 35°. The red belt is the median one starting at 31° E extending eastwards to 35° E. The most western is the purple belt encompassing the area between 27° E and 30° E and . The three belts are shown in figure (Ann.I.1)

Sinai and hence the current study region occurs in the blue belt of the ETM system.

The following parameters were used

Central meridian: 35°

Prime latitude :30°

False easting :300000

False northing :1100000

Scale :1.0

Map Units : Meters

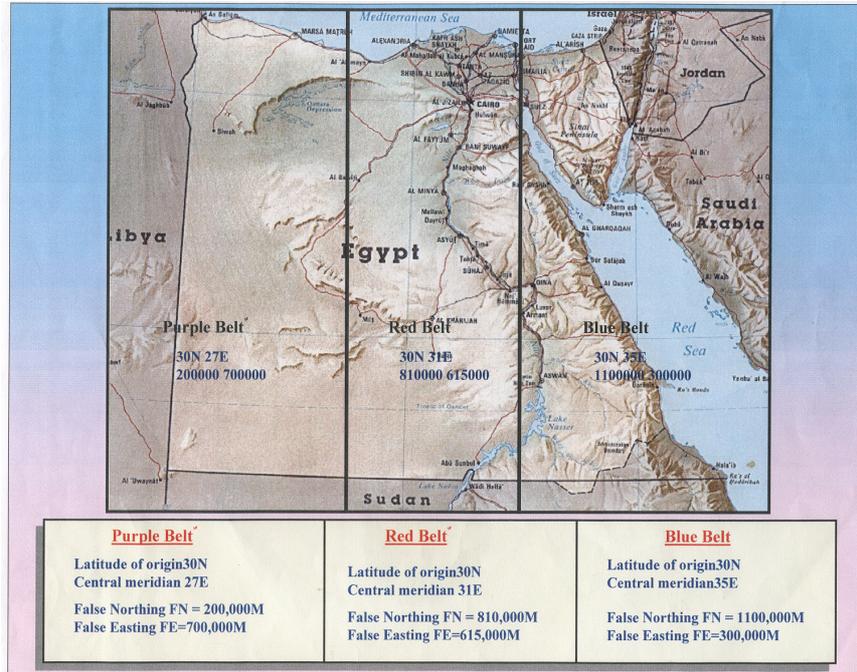


Fig (Ann.I.1) Egyptian Transverse Mercator projection and coordinate system.