Larks' Adaptation and Breeding Success in Kuwait State

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Abstract

This study aimed to examine the effectiveness of the protection measures currently in place to conserve the natural environment in Kuwait State. Comparison of protection effectiveness was based on the measurements of ecological habitat quality and biodiversity. In order to achieve this, 2 protected areas (SAANR and Kabd) and 2 comparable unprotected areas (B-SAANR and R-Kabd) were studied. In addition, an arable land area, the Pivot farm, was also studied. I examined the floral and avifaunal richness in these five areas. Distribution and abundance of members of the lark family *Alaudidae,* and the crested lark *Galerida cristata* in particular, were measured as a key habitat indicator. I also investigated the importance of water provison for wildlife. The diurnal use of a water hole and behaviour of crested larks during foraging and shading was observed. The challenge that larks face to cope with the high temperature during the breeding seasons was also examined.

The assessment of the vegetation identified the plant species richness as an index of habitat types, and this was examined in relation to human activity factors (e.g. grazing, camping, etc). Two-Way Indicator Species Analysis (TWINSPAN) showed three sample-groups of vegetation types (labelled A, B and C), a *Haloxylon* community (C); a sub-community (B: indicated by *Helianthemum*) of the *Stipa* community type; and a sub-community (A: indicated by *Plantago* and *Schismus*) of the mixed *Stipa - Cyperus* community type. Vegetation is a powerful indicator of land degradation in Kuwait. Richness of plant species was correlated negatively with land degradation.

Lark species were used as indicators to measure the benefit of the current conservation measures. There was a significant difference between lark density and species richness in protected, non-protected and arable lands. Density of larks was very low in non-protected areas, being about one individual km^{-2} (Figure 3.3). An obvious conclusion from the results was the important role of protected areas in conservation context. As an example larks' species abundance and density in SAANR were remarkably higher than B-SAANR (Figure 3.9 and 3.10). Furthermore, all other larks' species were absent in B-SAANR area in both breeding and non-breeding seasons.

This study showed the important role that a water hole can play in attracting wildlife in desert areas and in influencing several aspects of behaviour. Overall 96 animal species used the Talha water hole in SAANR, Kuwait throughout 2009. Talha water hole became an essential spot for attraction of most wildlife in the SAANR, especially in summer.

There may of course be cost associated with gathering in one place, such as at a water hole. Gregarious birds optimize vigilant attentiveness according to their group size. My study on the behavior of crested larks during winter and summer seasons in Kuwait revealed the presence of relationships between vigilance behaviours (head up, crest up and closed eye) verses group size. The study showed there are strong linkages between these behaviours and flock size. I found also a correlation between sitting individuals and having their crest up during shading. In addition, these vigilance behaviours were affected by the density of flocks. Hence, distance between foragers influences their social vigilance.

The breeding survey showed that larks face environmental challenges to breed in Kuwait. Absence of nests in unprotected areas B-SAANR and R-Kabd were correlated with their poor vegetation cover. Signs of larks breeding such as courtship display, protecting a territory or presence of nest were seen in the protected areas SAANR and Kabd. In SAANR, at least one of those signs was seen for greater hoopoe larks, crested larks and bar-tailed larks. In Kabd, juveniles of the black-crowned sparrow lark were seen.

Arable lands can play an important role for resident breeding species, especially in annual seasons that are characterised by a shortage of rainfall. For example, crested larks and doves were attracted to the Pivot farm. Territories and nests of crested larks were identified in alfalfa and barley crops. The Pivot farm possess potential characteristics that are absent in open areas and in protected areas. Crested larks were found mostly nesting in arable lands to compensate for poor habitat quality, low vegetation cover and rainfall shortages in protected areas. The effect of macro and microhabitat nest site selections on larks and doves thermoregulation was examined to determine the favourable position of the nest. Position and site location showed a remarkable effect on nest temperature. Further more, nest temperatures varied between different habitats and vegetation cover. The Pivot farm presents a good alternative habitat for crested larks to breed until mid-June.

To further study adaptations to warm weathers, I examined egg shell structure. A comparison of components of egg shell morphology reveals the presence of morphological and structural differences both between sibling species, and within the same species, collected at different latitudes. Two sibling species, crested larks *Galerida cristata* (from Kuwait) and skylarks *Alauda arvensis* (from the United Kingdom) have different egg volume, shell pigmentation and colour, thickness and water loss through the shell. The other sibling dove species showed difference in eggshell thickness between arid and temperate zones.

Within the same species, the house sparrow *Passer domesticus,* variation in eggshell thickness was also found between birds from Kuwait and the United Kingdom. The eggshells of house sparrows were thinner in Kuwaiti samples than in those collected in the United Kingdom. Moreover, within the United Kingdom there was also a similar latitudinal trend, with Scottish shell samples being thicker and those from further south in the UK being thinner. There was however little difference in water loss. In addition, average length and width of laughing dove eggs varied between South Africa and Kuwait samples. Hence, they differ in egg volume. These results suggest local adaptation in egg shell structure. Egg shell thickness increased at higher latitudes in both the sibling species, and in the within species, comparisons. This suggests that latitude, presumably via the effects of environmental temperature, can influence optimal eggshell structure, since the pattern was similar across the lark species compared with the within species variation in the sparrows. My data also reveal some variations among the eggshell characteristic of larks in response to temperature and latitude.

This study reveals the challenge that larks face to breed in Kuwait. To breed, a suitable secure habitat is essential. Habitat degradation was a remarkable in most non protected areas in Kuwait. Recommendations for conservation measures in Kuwait are discussed.

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Candidate's declaration

I declare that the work recorded in this thesis is entirely my own, except where otherwise stated, and that it is also of my own composition.

I further declare that no part of this work has been submitted as part of any other degree.

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Chapter 1: Introduction

1.1 Background to the study

Conservation biology has become a global discipline concerned with the scientific basis on which we might reduce or mitigate the threat to biodiversity that we now face. A rapid loss of species is now taking place. For example, the IUCN red list (2008) has documented that 12% of birds, 32% of amphibians and 28% of coral reefs in the world are threatened with extinction. Many plans and programs are underway by conservation practitioners to conserve and restore wild life, especially more threatened species. However, much effort is still needed and there is an increasing demand for land and resources for human use at the expense of wildlife (Okello *et al.* 2011). Conservation of a species often depends on its population size, local ecological system, adaptations, and evolutionary history and the politics and priorities of the countries in which it is found (Wood & Gross 2008).

Species population dynamics are influenced by natural (i.e. global/climatic change, migration, resources and food availability, physiological tolerance of species) and anthropogenic (human-induced) factors. However, anthropogenic factors such as habitat loss, fragmentation, disturbance, urbanization, human growth, introduced or invasive species, overharvesting, hunting, pollution might also interfere with natural factors by inducing inter and intra species competition, breeding success, mortality rate, diseases or parasites, predators (Wiens 1995, Côté & Sutherland 1997, Burke & Nol 1998, Zanette 2001, Brooks *et al.* 2002, Davis 2003, Harvell *et al.* 2002, McKinney *et al.* 2009, McKinney *et al.* 2012). Birds are conspicuous, mobile, relatively well studied, widespread creatures. Hence, they can play an important role as natural indicators of habitat biodiversity, and can be considered as a robust gateway to protect these habitats (Bock & Webb 1984, Evans 1994). Generally, habitat loss, overharvesting, pollution, introduced species and global/climate change are considered to be key factors in biodiversity loss that may influence the size of a bird population. Due to weather changes, habitat quality can be altered and therefore reduction of food abundance will constrain the breeding rate. For example, in 1985, when there was little rain and many plants were damaged by severe cold in Kuwait, crested larks *Galerida cristata*, temminck's horned larks *Eremophila bilopha*, black-crowned sparrow larks *Eremopterix nigriceps* and thick-billed larks *Rhamphocoris clotbey* did not breed. However, they did resume breeding when the weather became suitable (Clayton & Wells 1987). Population decline induced by natural factors such as weather and climate changes, predation and disease is still moderate and considered much less of a threat in comparison to non-natural factors (e.g. land use change) which alter habitats and may lead to an irreversible situation. For example, in Warsaw, Poland human activities alone account for about 43.8% of the loss of breeding crested larks while weather changes, corvid birds and domestic animals account for 15.6%, 9.4% and 6.3% respectively (Lesiński 2009). However, global warming is expected to have severe consequences for biodiversity loss as a long term effect (Thomas *et al.* 2004, Mayhew *et al.* 2007). About 40% of the biota in hotspots (56,000 endemic plant species and 3,700 endemic vertebrate specie) will be under threat of loss due to doubled carbon dioxide climates by 2106 (Malcolm *et al.* 2006).

Larks are highly abundant in the Mediterranean and low latitude regions (IUCN 2001). The decline in lark populations appears to be widespread. The population density of skylarks has declined in Great Britain over the last four decades (Chamberlian *et al*. 1999, Gillings *et al.* 2010 and Boatman *et al.* 2010). Crested larks were abundant in Central Europe in the middle ages (1200-1280), but their population in Switzerland declined dramatically after 1920 and the last breeding attempt occurred in 1991 (Hegelbach *et al*. 2003). In Kuwait, the number of crested larks has greatly reduced since 1979 prior to which it had been seen everywhere in huge assemblages; over thousand individuals were recorded in Ahmadi city in 1953 for example (Gregory 2005).

Changes in larks' population sizes as a result of changing land use and human activities are influence by the following factors in particular:

1.2 Global Threats

1.2.A Agricultural Activities

Changes in the composition and structure of steppe landscapes as has occurred for example in northern Spain due to agricultural activities, has meant that populations of some species, such as Dupont’s lark are now more threatened (Nogues-Bravo & Agirre 2006). Many years ago, skylarks were reported as serious agricultural pests in Iraq, grazing *Medicago sp*. leaves (Halse & Trevenen 1985) and in England, reducing sugar beet yield by grazing its young seedlings (Green 1980). As farmers aimed to enhance their crop yields, many farmland birds suffered and several bird species became victims of farming practices such as:

***1.2.A.1 Pesticides and Fertilisers*:** Using pesticides or insecticides to protect crops decreases the available food for skylarks (Chamberlain *et al*. 1999) and affects their reproductive success by reducing their fecundity (Topping *et al*. 2005). In addition, this has potential negative effects on other biological processes of larks (survival, mortality, dispersal), and annual declines in population density have been recorded in recent years (Topping *et* *al*. 2005). Furthermore, fertilisers have a long-term negative effect on soil microbial functional diversity (mainly organic carbon and nitrogen) (Hu *et al.* 2011) which might reduce farmland birds, such as yellow wagtails *Motacilla flava* by reducing their habitat suitability (Kovács-Hostyánszki *et al.* 2011). Heavy metals, such as lead, mercury and other toxic metals, showed a negative impact on biodiversity. Bioaccumulation of toxic trace metals in the food chain is a hazardous risk for animals and humans. For example, many studies showed high concentrations of heavy metals in egg contents and eggshells. Mora (2003) detected presence of Aluminum, Ba, Cr, Cu, Mn, Se, Sr, and Zn, in egg contents of yellow-breasted chats *Icteria virens*, yellow warblers *Dendroica petechia*, song sparrows *Melospiza melodia* and endangered southwestern willow flycatcher *Empidonax traillii extimus* Furthermore, Arsenic, Ni, Pb and V in were detected in eggshells of those species (Mora 2003). In addition, Lebedeva (1997) found accumulation of arsenic and lead in the bones of birds related to their food (earthworms), which were polluted by heavy metals. Also, the body mass was negative linked to the lead concentration in bird bones (Lebedeva 1997).

***1.2.A.2 Uniform Vegetation*:** While one type of crop maybe offer a good habitat for lark species in certain seasons, it might not be the optimal habitat throughout the year. For example, the abundance of skylarks increased in oat crops and decreased in wheat crops during the winter as a response to vegetation height and density in Castro Verde, Portugal (Delgado & Moreira 2002).

***1.2.A.3 Crop Alteration*:** Sowing regimes in lowland farms in England replaced spring-sown cereals, the predominant crops during the 1970s, with winter cereals (Chamberlian *et al*. 1999), which is too dense for Skylarks, especially in the breeding season, this is thought to have increased the decline of skylark populations (Chamberlian *et al*. 1999). Furthermore, seasonal changes in the height of crops drive shifts in nesting habitat during the breeding season (Chamberlian *et al*. 1999).

1.2.A.4 Intensive Agriculture: Modern techniques and technological progress have failed to take into account effects on the environment and its biodiversity. Using Herbicides to increase the area of farmland results in few weeds and as the harvesting efficiency is increased, the remaining grains that could be split on the field, and eaten by birds, will be less (Robinson & Sutherland 1999). Intensive agriculture also has negative health effects (see page 3: pesticides and fertilizers).

1.2.B Habitat Fragmentation

Most avifauna needs certain habitat types for foraging, shading from the sun, roosting and nesting. Thus, habitat fragmentation may alter species movements and may not provide enough patch size and interconnectivity of suitable habitats (Franklin *et al*. 2002). Consequently, discontinuity or isolation of patches for those birds that demand multiple habitats to fulfil their historical life requirements might be vulnerable to predation risk, limited resources and nest site location (Johnson 2007). For example, horned larks and meadow larks (grassland species) are affected by the decreases in the amount of grass-land as a result of shrub steppe fragmentation in the Snake River Plains of southwestern Idaho, USA (Knick & Rotenberry 1995). In addition, Dupont's lark *Cherosophilus duponti*, which is an endangered passerine representative of shrub steppe-like habitat, was found to be sensitive to the fragmentation of its habitat (Laiolo & Tella 2006 b). By using spatio-temporal models, Fahse *et al*. (1998) found that neither large nor high numbers of small protected areas provide the optimal solution for breeding of nomadic larks in the semi-arid area the Nama-Karoo, South Africa. They concluded that the breeding behaviour of nomadic larks depended on temporary habitats in which plants only grew after rainfall, and whose suitability might change annually. There is a need for long term field studies to determine precise breeding requirements, in order to be able to choose the best sites to establish protected areas(Fahse *et al*. 1998). Distribution patterns are a consequence of behavioural decisions. Many factors such as predator avoidance, shelter from weather and food quantity play a role in determining habitat preferences (Robinson & Sutherland 1999).

Effects of fragmentation might be more severe if the habitat patches become smaller than a species niche demands, particularly when their geographical ranges being near or surrounded by human land use such as camping or hunting. Consequences of fragmentation vary between species, where territorial species are likely to be more sensitive (Swihart *et al.* 2003). Hence, establishment of green corridors between habitats is considered an important issue in conservation of biodiversity rather than just preserving those habitats themselves.

1.2.C Global Warming

The physiology, phenology and adaptations of plants and animals may be affected by global warming. However, it can be difficult to disentangle other factors. For example, the body condition (the ratio of body mass (g) to tarsus length (mm)) of graceful warbler *Prinia gracilis*, Sardinian warbler *Sylvia melanocephala*, house sparrow *Passer domesticus* and yellow-vented bulbul *Pycnonotus goiavier* (but not crested larks) declined significantly in Israel between 1950 and 1999 (Yom-Tov 2001). The Considerable expansion of the crested lark, a warmth-seeking species, in Switzerland, where the temperature decreased slightly between 1850 and 1900 was followed by a remarkable decline in their breeding population in most of Switzerland after 1930, suggesting that the disappearance of crested larks was not correlated with climatic changes but was the result of the decline in suitable habitats (Hegelbach *et al.* 2003) or due to other factors like food shortage which is a possible factor that might have influence the decline in body mass in Israel, (Yom-Tov 2001).

1.3 Kuwait Ecology

The State of Kuwait is located at the eastern corner of the Arabian Peninsula and on the northwestern part of the Arabian Gulf (Figure 1.1).

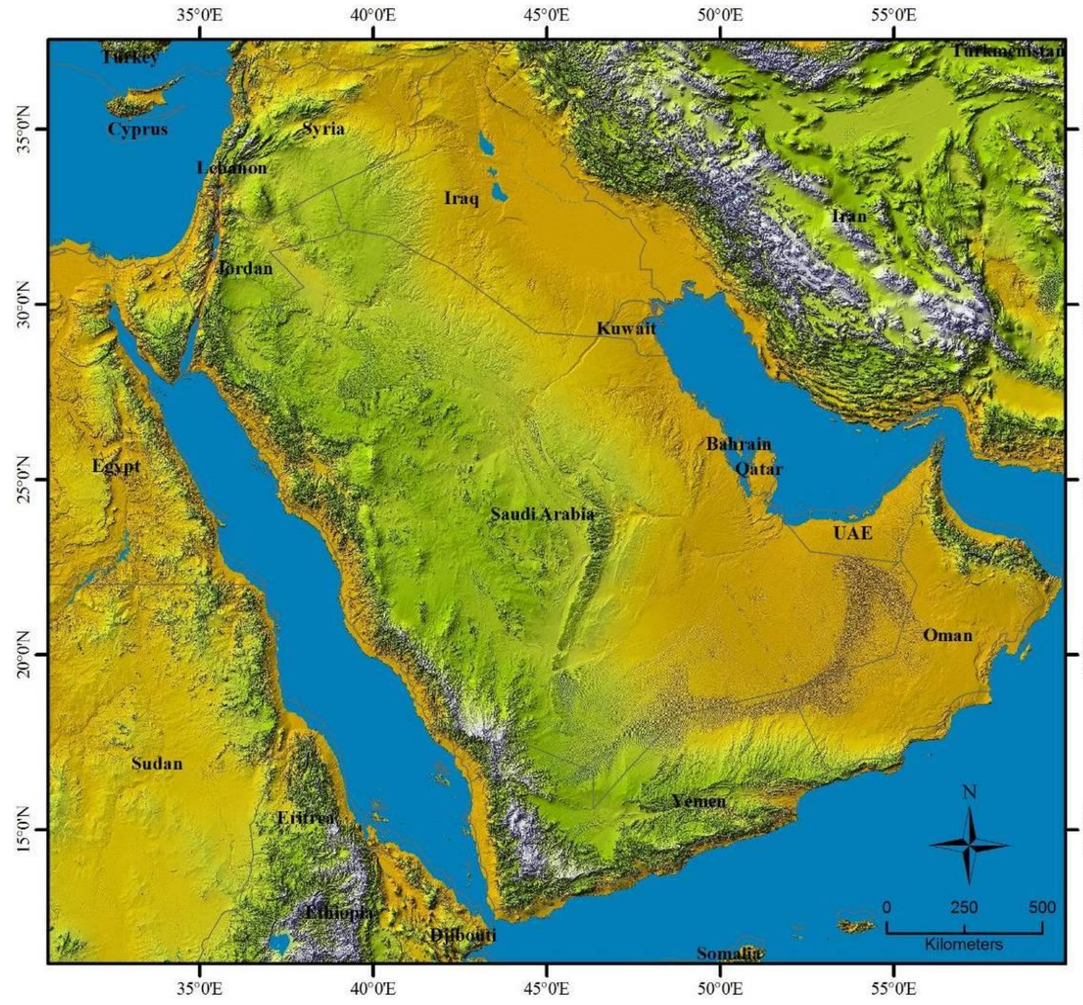


Figure 1.1 Location of State of Kuwait in the Arabian Gulf

Kuwait is approximately 18,000 square kilometers in area and is situated between 28˚30' to 30˚05' North and 46˚33' to 48˚26' East (Figure 1.2).

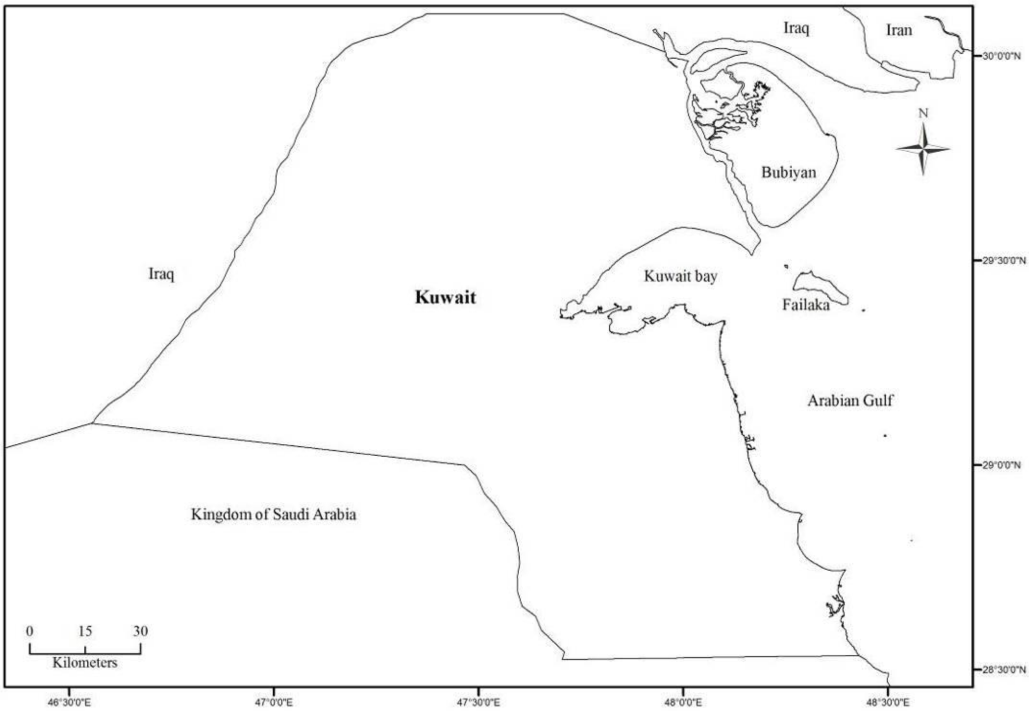


Figure 1.2 Location of State of Kuwait in the Arabian Peninsula

It has 550 kilometers of shoreline. Most of the land area of Kuwait is desert, without permanent or temporary lakes. Its topography is mostly flat, rising gradually from sea level in the east, where coastal areas are located, to up to 300 meters above sea level in the west border area adjacent to the Kingdom of Saudi Arabia (Figure 1.3). The Jal Ai-Zor escarpment, the most famous topographical feature in Kuwait, is up to 145 meters above sea level. Low, scattered sand dunes are spread along coastal areas from Kuwait bay to the south. Overall, desert habitat represents no less than 90% of the total Kuwait terrestrial area.

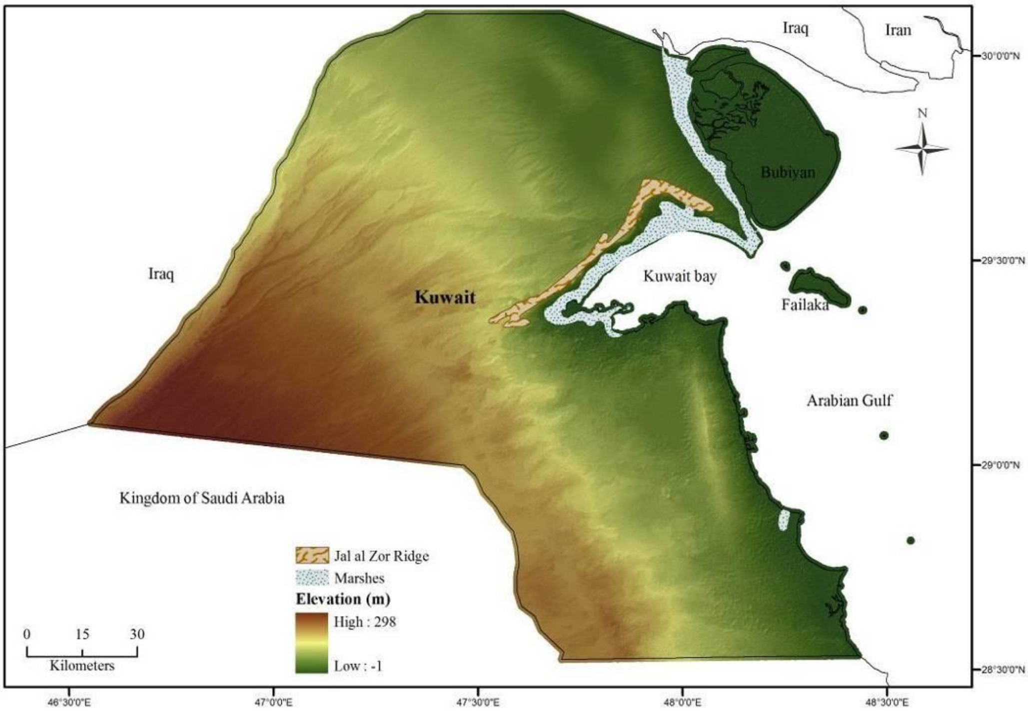


Figure 1.3 Topographical features in Kuwait State

1.3.1 Climate

Kuwait is located in the semi-arid zone, and its continental climate is categorized by two distinct seasons: a short, relatively cold winter (November-February) and a long hot summer (March-October). Winter temperature drops to its lowest level in December and January (2-3˚C) during night time (Figure 1.4). Occasionally, the temperature drops to 0°C or even slightly below freezing during December and January. The lowest temperature so far recorded is -4°C, registered in 1964 (Ministry of Information 2001).

On the other hand, Kuwait is subjected to very high temperatures in summer, especially in June and July when the sun becomes almost perpendicular in the sky. At this time, day length is up to 14 hours and maximum temperatures rise up to 51 °C in the shade (Ministry of Information 2001). In Kuwait, the highest temperature is usually recorded after midday time from one to three after noon, where soil temperature reaches about 85˚C during August (KISR 2000).

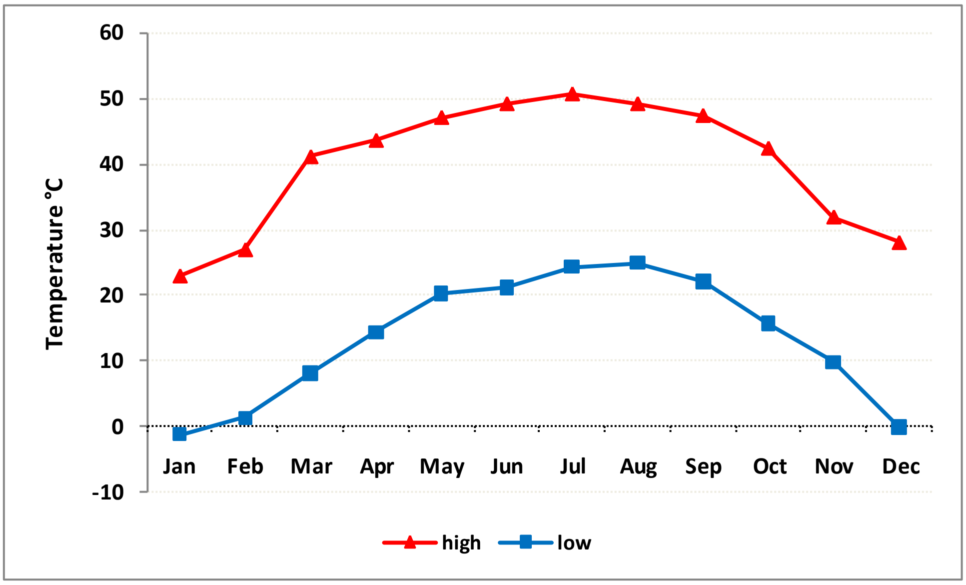


Figure 1.4 Maximum and Minimum temperatures in Kuwait State (Modified from Kuwait Civil Aviation 2010).

1.3.2 Rain

Kuwait rainfall levels are characterized by high fluctuation from one year to the next (Figure 1.5), with the average being 118mm/year (Kuwait Civil Aviation 2010). During winter, cyclonic rains fall on Kuwait while, in the beginning and at the end of winter, seasonal convectional rains fall. Convectional rains are correlated with unstable states accompanied with thunderstorms named locally "Sarayat".

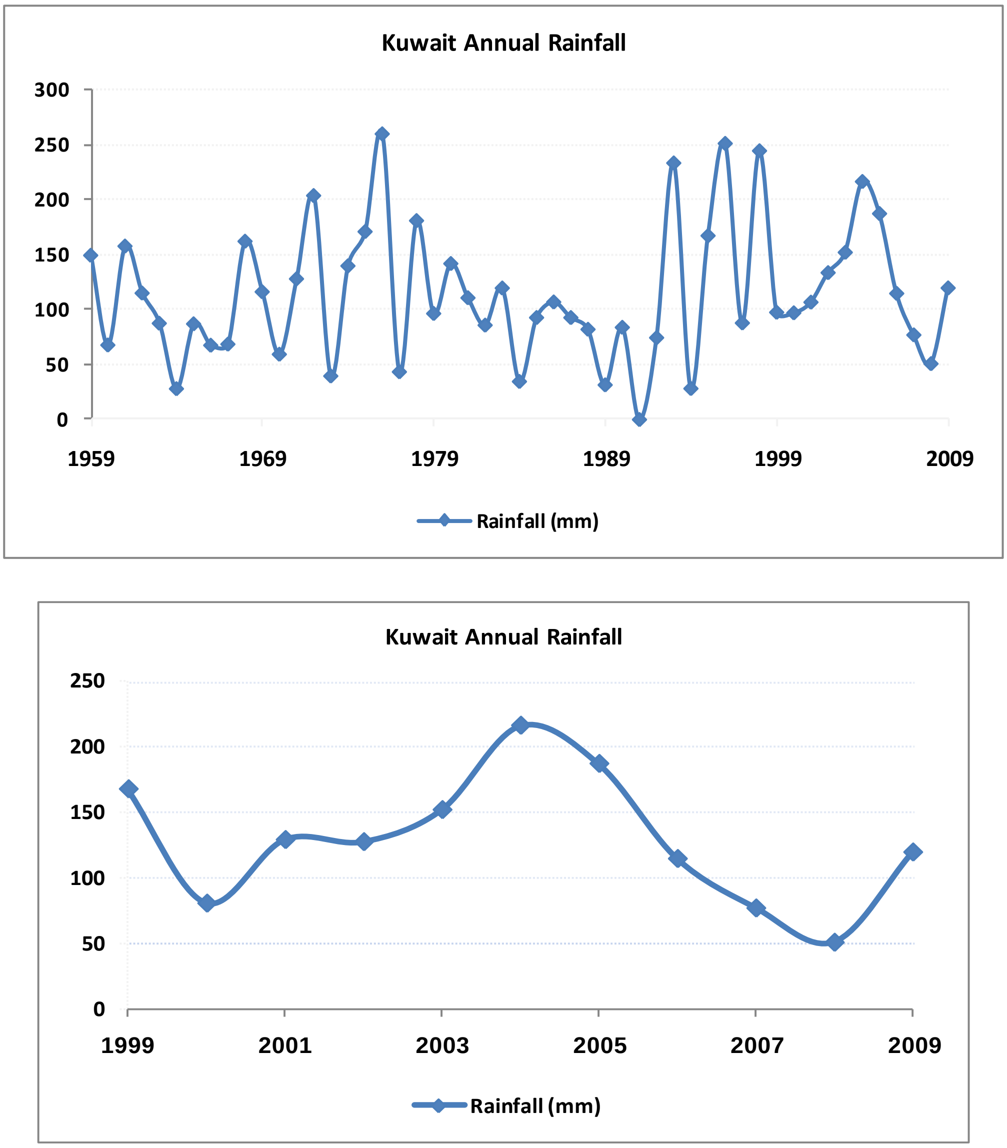


Figure 1.5 Annual rainfall in Kuwait State (Modified from Kuwait Civil Aviation 2010).

The drought season is from May till mid-October with long periods of solar radiation, low or no rainfall (Figure 1.6), and low relative humidity.

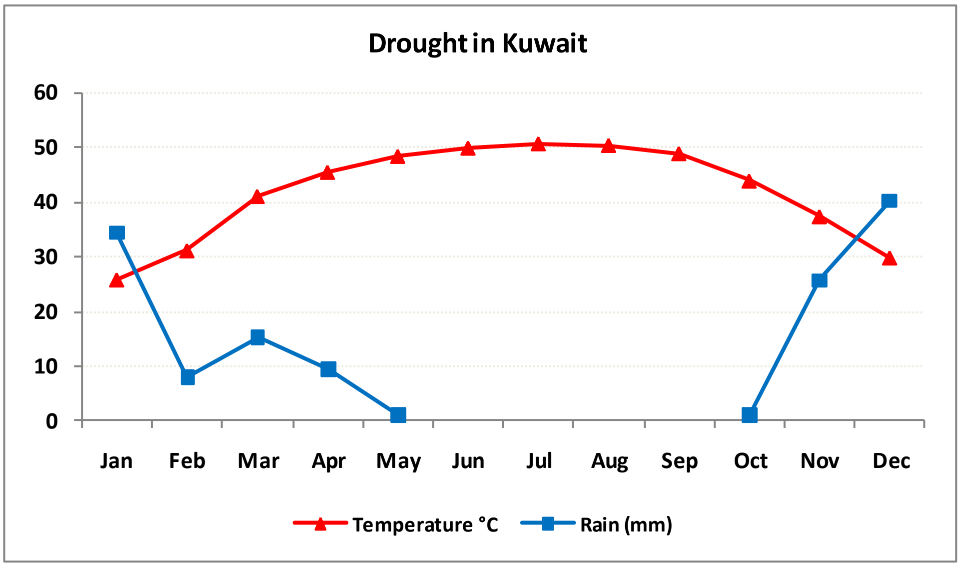


Figure 1.6 Monthly average maximum temperature and average rainfall (Modified from Kuwait Civil Aviation 2010).

Consequently, transpiration processes in plants increase and annual species start to dry up and die away. Native perennial species have specific structural modifications in their leaves, stems and roots to tolerate drought and hot weather.

Relative humidity in Kuwait varies seasonally and declines to its lowest level (about 25%) in summer and rises up to its highest level (about 80%) in winter (Figure 1.7 and 1.8).

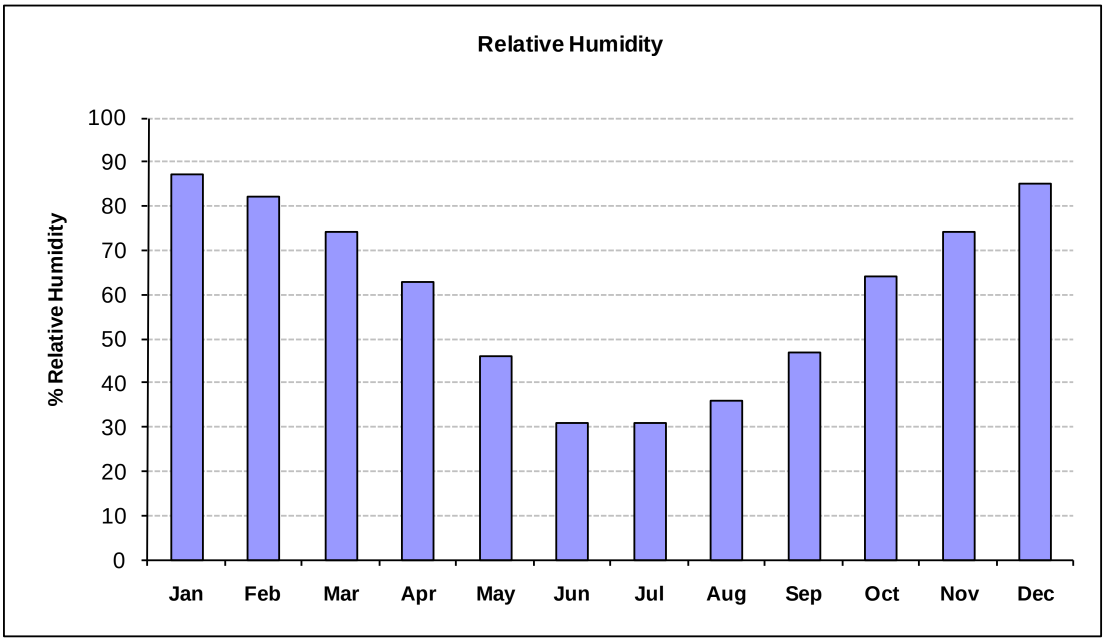


Figure 1.7 Relative Humidity in Kuwait State (Modified from Kuwait Civil Aviation 2010).

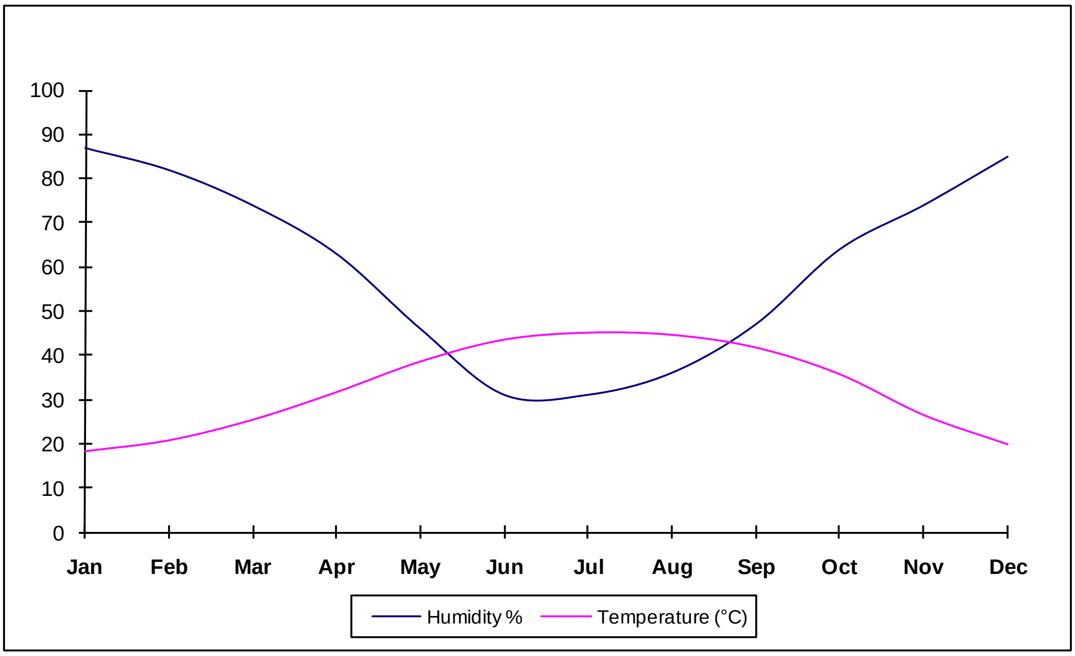


Figure 1.8 Relative Humidity and Temperature in Kuwait State (Modified from Kuwait Civil Aviation 2010).

1.3.3 Winds

Most of the year, the prevailing winds blow from the northwest direction and comprise about 43% of total winds, while the less dominant winds are south easterlies and (around 19% of the total winds). In the absence of the dominant winds, coastal areas can be affected by local winds known as desert and sea breezes, which occur due to differences in temperature between land and sea (Al-Ajmy & Safer 1987). The highest wind velocity slightly exceeds 5m/s (11.2 miles/hour) during June and July (Figure 1.9) causing sand drifting and sand dune movements.

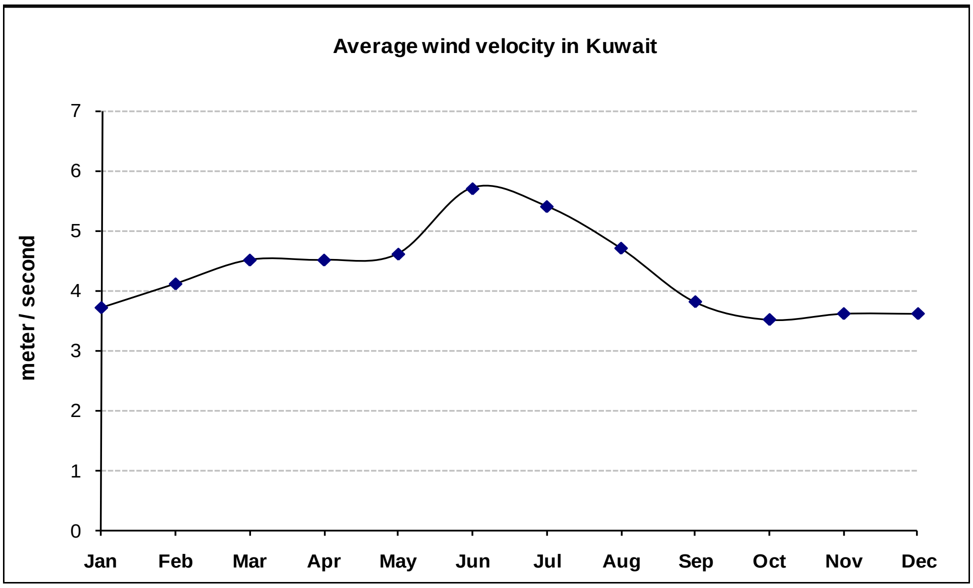


Figure 1.9 Wind speed in Kuwait State (Modified from Kuwait Civil Aviation 2010).

The prevailing winds blow from the northwest, which is hot and dusty in summer and very cold in winter.

1.3.4 Soil

Most areas are characterized by shallow soil depth varying from a few centimeters up to about two meters. Sand, gravel and mud are the dominant soils (Figure 1.10). The concentration of total dissolved salt is high in the surface layer of soil due to intensive evaporation and scarcity of rainfall. Agricultural soil is quite poor and lacks most of the metals and the basic elements necessary for plant growth as well as having poor water retention due to high permeability and low content of organic materials and silt (Misak *et al*. 1998).

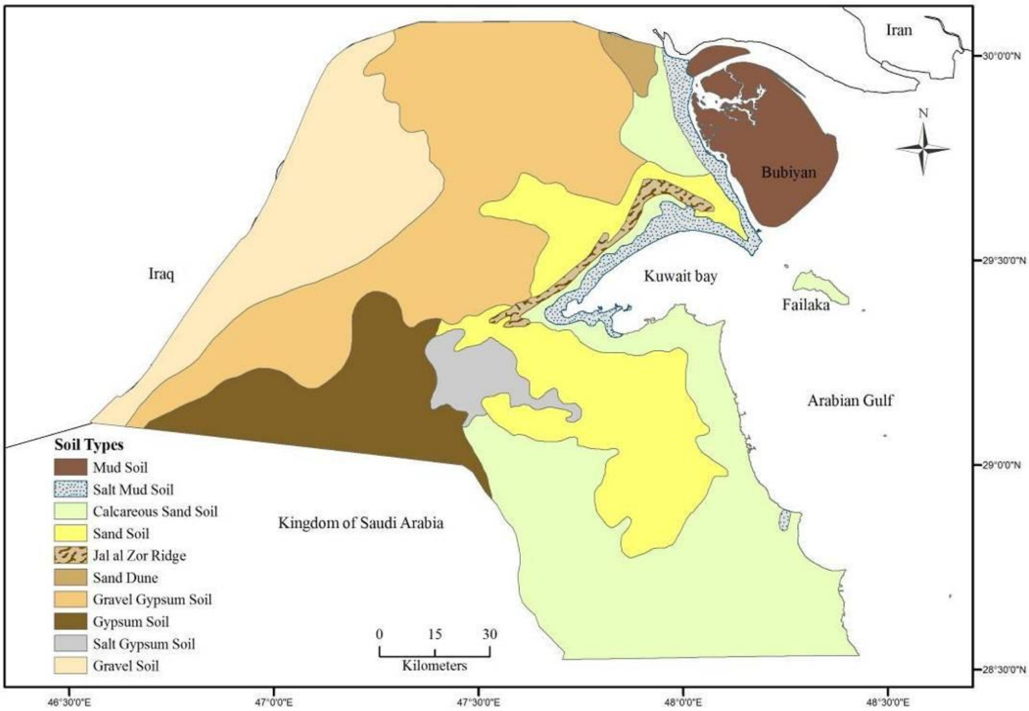


Figure 1.10 Soil types of Kuwait State (KISR 1993)

1.3.5 Vegetation

Plant cover is generally determined by geomorphology, soil type and depth and climate of a region. Kuwait is mostly a flat sandy land characterized by four ecological systems: 1) Sand dune ecosystem; 2) Coastal plain and lowland ecosystem; 3) Desert plain ecosystem; and 4) Desert plateau ecosystem (El-Shora & Jasim 1996).

The desert plain ecosystem occupies the greater part of the country and contains three main communities; *a) Cyperus* steppe, *b) Rhantarium* steppe and *c) Haloxylon* steppe (Figure 1.11and 1.12), (Halwagy & Halwagy 1974).

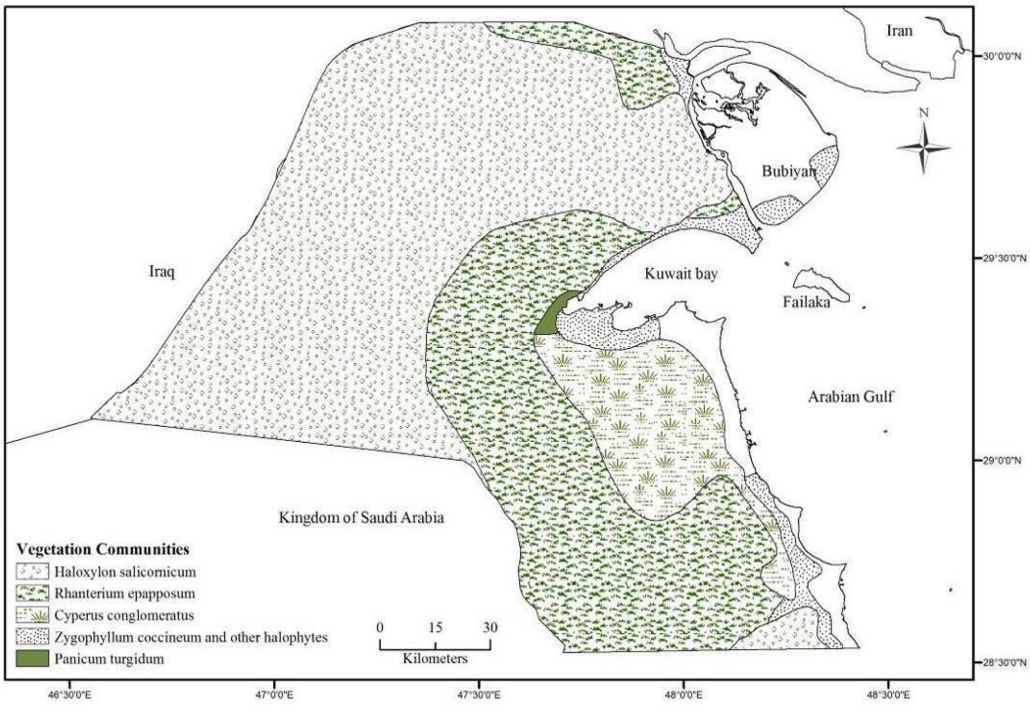


Figure 1.11 Plant Map of Kuwait State (Halwagy & Halwagy 1974 modified)

Figure 1.12 Pattern of vegetation cover in protected areas in Kuwait. Most plant communities are composed of scattered dwarf shrubs about 50-60cm.

Vegetation is categorized by few grassy herbs and short scattered shrubs. Halwagy and Halwagy (1974) described the vegetation of Kuwait "as a poor open scrub of under-shrubs, perennial herb and ephemeral species". He also added that tall shrubs are restricted to favourable sites only and rarely reach over two meters.

Studies on the flora of Kuwait have revealed 374 native and naturalized plant species from 55 families; 256 species (68.4%) are annuals, 34 species (9.1%) were shrub and under-shrubs and only one species, (0.3%) was tree, whereas herbaceous perennials were represented by 83 species (22.2%) of flora (Boulos & Al-Dosari 1994). Dickson (1955) classified Kuwait vegetation cover into four plant communities: 1) Haloxylon; 2) Rhanterium; 3) Cyperus and 4) Panicum. Subsequently, five plant communities were recognized in Kuwait State (Kernick 1966, Halwagy & Halwagy 1974). Recently, Omar *et al*. (2001) defined eight dominant plant communities: 1)Haloxyletum; 2)Rhanterietum; 3)Cyperetum; 4)Panicetum; 5)Stipagrostietum; 6)Zygophylletum; 7)Centropodietum; and 8)Halophyletum; this was done by integrating soil and vegetation information in an Geographical Informational System (GIS) see (Figure 1.13). The change in dominant plant communities through a few decades is attributed to natural and human factors. The original dominant plants have been replaced by a secondary dominant plant due to overgrazing, quarrying or other ecological disturbances (Omer *et al*. 2000).

Distribution and abundance of dominant perennial shrubs has declined and been replaced by grassy and annual plant or spiny species (Halwagy & Halwagy 1974 and Omer *et al*. 2000). Open land in Kuwait will reach the climax ecosystem when it is mostly occupied by *Rhanterietum epapposum* or *Haloxylon salicornicum* perennial species and moderate when Cyperus conglomerates predominate; the habitat is in poor condition when *Cornulaca* and/or annual forbs increase to reach barren land status (Omer *et al*. 2000).

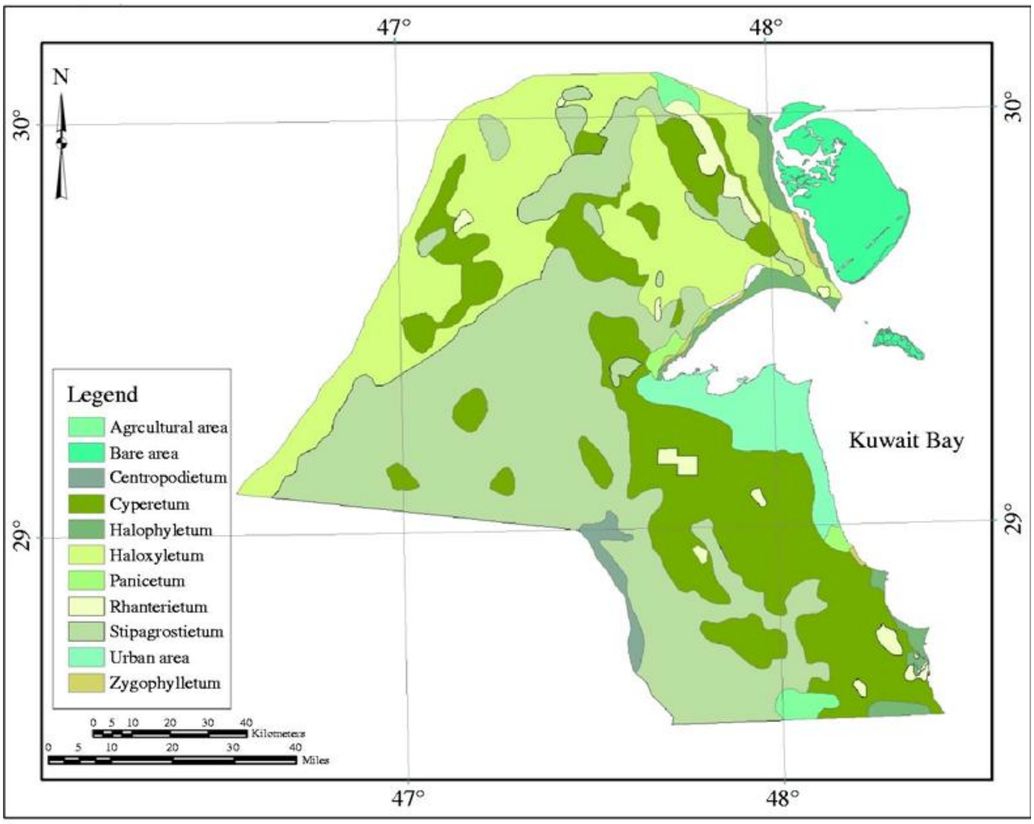


Figure 1.13 Plant Map of Kuwait State (Omar et al. 2001)

Silviculture along roads, avenues, roundabouts and parks cover about 43km2 and about 648520 trees. Farm lands cover about 24,000 hectares, from which 5,000 hectares were planted and distributed into three areas: 1)Wafra 370 farms, 2)Abdali 156 farms and 3)Sulibia 33 farms mainly for cow and sheep breeding (Environment Public Authority 2003).

In Kuwait, natural vegetation cover was destroyed over the entire desert lands (Khalaf & Al-Ajmi 1993) and this became an indicator of land degradation (Al-Awadhi *et al*. 2003). Natural vegetation covers less than 10% of many land areas in Kuwait (Al-Awadhi *et al*. 2003).

Intensive human activities combined with fragile ecological conditions in Kuwait have accelerated environmental degradation; annual land desertification is approximately 285 square kilometers (Al-Awadhi *et al*. 2003) and average annual sand drift is $20m^3$ (Khalaf & Al-Ajmi 1993).

1.4 Assessing the effectiveness of conservation measures in Kuwait

Larks are resident passerine representatives of shrub steppe habitats (Laiolo & Tella 2006 a). But, only a few of them can breed in the desert ecosystem. They are thought to possess a number of characteristics that enable them to be used as indicators of the habitat's integrity (Martin & Possingham 2005).

In order to use them for this purpose in Kuwait State, it is important to quantify lark population density and breeding success in areas subjected to different land use and conservation measures. The following different areas were used in to determine the habitat and abundance of larks:

1.4.1 Protected Areas in Kuwait

There are several areas of Kuwait that are protected. These are listed below.

a) Sabah Al Ahmed Reserve is a protected area (330 km^2) located on the north west of Kuwait bay and characterized by significant landscape features. It contains different habitats; desert plain (shrub steppe), Am-Arimum depression (playa deposit), escarpment (rocky ridge), coastal desert plain and marshland habitats. 139 plant species (El-Shaik & Abbadi 2004) 21 reptilian species and 151 bird species have been identified (Omar & Al-Shuaibi 1986).

b) Jahra Pool Reserve is a reed coastal protected area (3 km^2) considered as one of the most important areas for monitoring birds in Kuwait (Evans 1994).

221 avifauna species were been recorded in Jahra Pool Reserve including globally threatened species such as houbara bustard *Chlamydotis undulata*, lesser kestrel *Falco naumanni*, Egyptian Vulture *Neophron percnopterus* and greater spotted eagle *Aquila clanga* (Al-Shehabi 2009). In addition, it provides a breeding habitat for several water birds such as coot *Fulica atra*, moorhen *Gallinula chloropus*, little grebe *Tachybaptus ruficollis* and black winged stilt *Himantopus himantopus* (Al-Ghanem & Al-Shehabi 2006).

c) Doha Reserve is a coastal protected area **(**4.5 km^2) considered as an important area for monitoring birds (Evan 1994) especially water bird species such as crab plovers. It is characterized by a sand muddy marsh land where Kentish plovers nest.

d) Sulaibikat Reserve is a small coastal protected area less than (1 km^2) attracts shore birds such as plovers.

e) Kabd Research Center, which is 40km^2, is a terrestrial protected area in the west. It is generally a short and sparse grass steppe habitat, divided into sections (e.g. grazed, non-grazed land) for different scientific research purposes such as evaluating the impact of continuous grazing and rotational grazing on vegetation recovery and farm range stabilization.

1.4.2 Non-Protected Areas

These are for comparison with the above protected areas. Two unprotected areas that have similar landscape and ecological features to SAANR and Kabd had been chosen for this purpose. The first one is behind Sabah Al-

Ahmed Natural Reserve (B-SAANR), 80km^2 and the second is right-hand of Kabd Scientific Research Station (R-Kabd), 40km^2.

1.4.3 Farmlands

Kuwait Farmlands vary from few to several ten hectares, and are located mainly in two areas: **Al-Abdaly** which in the north and contains 156 farmlands and **Al-Wafra** which is in the southwest of the country and contains 370 farmlands (Environmental Public Authority 2003). Their crops are mainly vegetables, while some farms do not sow at all and are kept for leisure only.

1.5 Kuwait Threats to Birds

The study is focused in particular on avian conservation in Kuwait. Kuwait is potentially a harsh environment for birds since the climate is extreme and many areas are effectively desert. This presents considerable challenges to breeding birds. Furthermore, the country is relatively small, and the suitable land is heavily used by human activities. It is recognized that it is important to conserve natural habitats, but protected areas are limited to one large and four small reserves. It is important that we have a good understanding of the effectiveness of such protection, and of the best ways of protecting and monitoring change in the ecosystems represented. Indicator species are a useful tool in this context, and it is well proven that birds are good bio-indicators of the health of ecosystems where they are conspicuous, familiar and abundant (Bock & Webb 1984). Abundant bird species (such as shore larks *Eremophila alpestris*, lark *sparrows Chondestes grammacus* and grasshopper sparrow *Ammodramus savannarum*) in Southeast Arizona are valuable indicators of environmental condition (Bock & Webb 1984). Also, indicator species could be a small set of species (Fleishman *et al.* 2005) on well known representative taxa such as threaten and/or endemic species (Bonn *et al.* 2002).

In total, 365 avian species have been recorded in Kuwait State in spite of its small area and harsh climate (Kuwait Environment Protection Society 2007). But, probably only 24 of them are breeding, of which 8 species breed regularly while others probably mate in the country during winter visits (Evans 1994).

In addition to the global factors mentioned above, conservation problems in Kuwait mainly arise from the following:

1.5.A Over Grazing

Livestock grazing is one major process by which habitat structure is altered and desertification increased (Al-Awadhi *et al.* 2003, Al-Awadhi *et al.* 2005) (Figure 1.14). Most bird species decline with increasing grazing pressure (Martin & Possingham 2005) due to absence of habitats or poor habitat quality. As grazing increases, vegetation cover is reduced and granivorous birds decrease despite the presence of soil invertebrate feeding species (Buckingham & Peach 2005). In an attempt to measure the impacts of grazing on avifauna in Australian woodland, foraging behaviour was examined and foraging height preference was found to be a good predictor of species' susceptibility to grazing pressure, where bird species decline as grazing pressure increases, and birds showed both monotonic and non-monotonic responses to grazing (Martin & Possingham 2005). In Kuwait, about 75% of the areas are used for livestock grazing (Omar *et al.* 2003). The wide spread plant species *Rhanterium epapposum* which formed 25 % of dominant communities in Kuwait (Halwagy & Halwagy 1974), its community recently only covers 2.1% of the total area of Kuwait (Omar & Bhat 2008). Moreover, *Rhanterium epapposum* which is highly susceptible to grazing (Omar & Bhat 2008) has become only confined to protected areas (Omar *et al.* 2001). Accordingly, we might expect grazing pressure to influence bird abundance in Kuwait.

Figure 1.14 Excessive grazing effect on desert lands in Kuwait. Top left photo shows a sample structure style of the vegetation cover in protected areas PAs and non-protected areas NPAs. Right up and down photo shows the effect of grazing on vegetation cover in non-protected areas NPAs.

1.5.B Direct human disturbance

Camping is a traditional habit in several Arabian Gulf countries. A camp area varies from 1000 to 5000m^2 and about 20 to 50 people are involved on average. In most cases, the camp area is treated by a tractor to make the land of the camp plain to ride 4wheel motor bikes, play football and/or volleyball. The extensive use of these 4wheel motor bikes in the camp areas and surrounded areas in addition to off-roads has a high impact on the environment. The land of the camp becomes compacted where wild natural plants have a very weak chance to grow. In addition, the loose surface layer on the camp land becomes vulnerable to erosion and weathering. Camping areas turn to severe barren habitats, with a lack of perennial plants and wildlife biodiversity. However, camping has become something of a phenomenon in Kuwait, where the camping habit has become exaggerated and widespread in most desert lands. About 60 percent of desert land is occupied for this purpose every year in Kuwait (Environment Public Authority 2003) from November to April (Figure 1.15). This causes considerable disturbance to bird populations and to other wildlife.

Figure 1.15 The effect of camping recreational activity on vegetation cover in desert lands of Kuwait. Both upper and lower photo show compacted soil and absence of plants due to excessive off-road vehicle tracks.

1.5.C Hunting

Bird hunting is a serious problem facing migratory birds in several Mediterranean countries. More than 270,000 passerine birds were captured in Egypt for food each autumn and up to 11,000 birds were trapped annually in Saudi Arabia for economic benefits such as food or for trade as pets (Felemban 1995). Unfortunately, unpublished reports indicate that hunting is responsible for the death of a very large number of migratory birds of many species every season in Kuwait for food consumption or fun (pastime/amusement) purposes. Low awareness, and few secure or suitable habitats, restrict breeding success or even prevent breeding attempts. Startle responses of most bird species, in addition to crushed nests in different habitat ecosystems, are widespread due to the disturbance caused by hunters.

1.5.D Habitat Fragmentation

Despite the presence of some protected areas in Kuwait, there is a risk facing bird species as a consequence of habitat fragmentation (Figure 1.16). While birds move from one habitat to another looking for food or shelter or other demands they are being vulnerable to the risk of hunting. Particularly, in case of those small protected areas (Jahra pool reserve, Doha reserve and Sulaibikhat reserve).

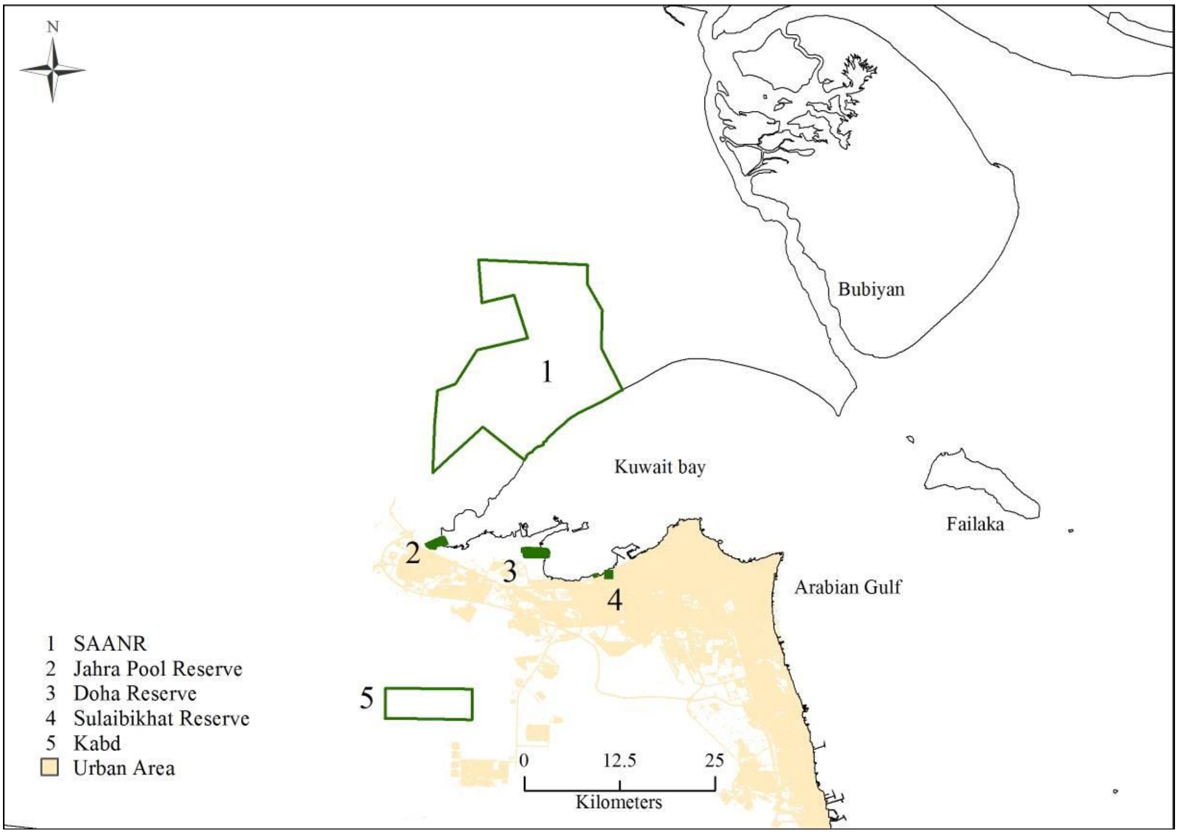


Figure 1.16 Geographical distribution of protected areas in Kuwait. Protected areas are fragmented by urban areas and other anthropogenic land uses. Absence of green corridors is clear.

As mentioned above, overall this study is focused on Kuwait ecology and its avian species, particularly on larks. I examined the effect of current land use on bird distribution and abundance, plant communities and bird behaviour. In addition, I also examined the thermal challenge experienced by breeding birds in Kuwait, and how this affects eggs and incubation. Below I first give a summary of the ecology of Kuwait, followed by a description of the aims of the project and of the study species.

1.6 Using larks to study conservation effectiveness in Kuwait

Broad aims of this study

Birds are relatively well studied, widespread, creatures, so they can play an important role as natural indicators of habitat biodiversity, and can be considered as a robust gateway to protect these habitats (Evans 1994).

This study investigated the distribution of larks in relation to land use patterns in protected and non-protected areas of Kuwait. This enabled me to gauge the threats to biodiversity, and the efficacy of current conservation measures. I also investigated some aspects of their adaptation to Kuwait's semi-arid climate where water is limited and temperature is extremely high.

Avifauna forms the majority of Kuwait wildlife, and larks probably are the most well known bird species. The yearly loss of adults, nests and juveniles of resident breeding species may be more than can be compensated for by immigration of breeders from other areas, due to continuous land degradation and habitat destruction. On the other hand, it is impossible to declare all the important bird sites as protected areas, so it is necessary to secure bird habitats by good planning and management. However, ecological habitats and their biota are exposed to degradation due to human population growth and urban expansion, accompanied with the difficulty of evaluating the real value of biodiversity and low public awareness. This study was therefore particularly concerned with evaluating the effect of habitat protection on the avifauna, by comparing this with unprotected areas.

1.6.1 Lark Biology

Larks are passerines, widespread and found typically in sparse steppe vegetation lands. They are highly abundant in the Mediterranean and low latitude regions. Even though they are classified as ‘low concern’ species (IUCN 2001), their populations have declined in recent decades and some species as Dupont’s lark *Chersophilus duponti* have been pronounced as nationally threatened in some European countries. Eleven out of 15 European lark species visit Kuwait during the migration seasons (Table 1.1), but only four of them have been recorded as breeders (Gregory 2005).

Table 1.1 Larks Species in Kuwait State IUCN Category: LC ver 3.1 (2001)

Status	**Scientific Name**	**Common Name**
breed	*Alaemon alaudipes*	greater hoopoe-lark
visitor	*Alauda arvensis*	Eurasian skylark
breed	*Ammomanes cinctura*	bar-tailed lark
visitor	*Ammomanes deserti*	desert lark
breed	*Calandrella brachydactyla*	greater short-toed lark
visitor	*Calandrella rufescens*	lesser short-toed lark
visitor	*Eremophila bilopha*	temminck’s lark
breed	*Eremopterix nigriceps*	black-crowned sparrow-lark
breed	*Galerida cristata*	crested lark
visitor	*Melanocorypha bimaculata*	bimaculated lark
visitor	*Rhamphocoris clotbey*	thick-billed lark

Their morphological features (body size, bill shape, plumage ground colour) vary from one region to another according to historical isolation and different environmental factors as a result of natural selection or phenotypic plasticity (Guillaumet *et al*. 2006). Seed, fruits, maybe small grasses or leaflets and insects comprise their main diet. They are mostly monogamous, open ground nesting birds, and defend a territory during the breeding season. In West Asia, particularly in the Arabian Gulf Countries, larks breed in summer from March to June. Mostly, the female is the incubator and the male is the territory defender while both parents care and feed the young (Cramp *et al*. 1988). In this section, I describe relevant aspects of their ecology and life history.

1.6.2 Desert larks' life history

Birds in arid climatic areas are thought to have several physiological adaptations to their environments. Williams documented that desert larks have a metabolic rate, total evaporative water loss and respiratory water loss that is lower than those mesic species within the same family; also he found that desert larks have small clutch sizes and slow nestling development compared to the temperate species (Williams *& Tieleman* 2005).

Crested larks, a ground foraging passerine species, are resident in Kuwait (Cramp *et al.* 1988). Crested larks were abundant in Central Europe in middle ages (1200-1280), but their population declined dramatically after 1920 (Hegelbach *et al.* 2003) in several countries such as Poland (Lesiński 2009) and the agrarian landscape of Italy (Massa & La Mantia 2010). In Lithuania, crested larks were classified as endangered species (Lithuanian Red Data Book 1992, Zalakevièius 2001) and in Switzerland the last breeding attempt occurred in 1991 due to the decline in suitable habitats (Hegelbach *et al.* 2003).

1.6.3 Habitats

Lark habitat requirements vary from one species to another, but, generally, they are restricted more or less to sparse and short vegetation. Wintering skylarks *Alauda arvensis* in farmland prefer vegetation height from 1 to 10cm and ground cover ranging from 10 to 75% (Eraud & Corda 2004). However, uniform vegetation structure due to grazing affects the densities of lark bunting *Calamospiza melanocorys* and horned larks *Eremophila alpestris* (Fontaine *et al*., 2004). Therefore, heterogeneity of vegetation is important to their survival, and diversity of vegetation community types will influence habitat structure. Serrano and Astrain (2005) found lesser short-toed lark and short-toed lark using different microhabitats for different behaviours (*Salsola* for nesting, less cereal for feeding, and *Artemisia* for singing). Hence, microhabitat preferences should be considered rather than simply overall natural vegetation cover to conserve steppe birds (Serrano & Astrain 2005).

Species abundance depends on habitat type and vegetation structure; skylarks have been found to prefer arable lands with relatively low vegetation as macro habitats, whereas they prefer stunted growth such as shallow depressions, cultivated plots and edges of narrow tarmaced farming roads as microhabitats. Therefore, this stunted vegetation growth should be constructed or at least preserved (Schoen 2004). Furthermore, creating plots and small rectangular patches of bare ground within autumn-sown cereals appear to provide the benefits of spring-sown cereals at very low costs. Skylarks have been found to produce more chicks in fields with these kinds of plots than in those without. On one farm in southern England, the skylark population more than doubled after the introduction of such skylark plots (Donald & Morris 2005).

However, in contrast to the reported effects of these microhabitat changes, models of habitat association for some species (like horned larks *Eremophila alpestris*), designed to test the hypothesis that habitat change influences the distribution and abundance of passerine birds breeding in shrub steppe habitats of southwestern Idaho, showed it was significant only at large spatial scales (Knick & Rotenberry 1997).

A strong decline in the population of crested larks in Warsaw, Poland was recorded from 1986 and it became totally extinct in 2006 (Lesiński 2009). Furthermore, body condition of crested larks (mass of body to tarsus length ratio) decreased in Palestine between 1950 and 1999 due to global warming (Yom-Tov 2001). In Kuwait, the crested lark has greatly declined since 1979 prior to which it had been seen everywhere in huge assemblages; thousand of individuals were recorded in Al-Ahmadi city in 1953 for example (Gregory 2005).

Due to weather changes, habitat quality can alter. For example, in 1985, when there was little rain and many plants were damaged by severe cold in Kuwait, crested larks did not breed. However, they did resume breeding when the weather became suitable (Clyton & Wells 1987). Crested lark morphological features (body size, bill shape, plumage ground colour) vary from region to region according to historical isolation and different environmental factors as a result of natural selection or phenotypic plasticity (Guillaumet *et al.* 2006); 37 races of crested larks have been recognized and 2 subspecies a) *Galerida cristata cristata* "short-billed" and b) *Galerida cristata randonii* "long-billed" were identified in Morocco by using mitochondrial and nuclear DNA sequences (Guillaumet *et al.* 2006). Crested larks are monomorphic species and it is difficult to recognize the sex of adults, but females maybe distinguished by their slightly shorter crest (Cramp *et al.* 1988). They are mostly monogamous, open ground nesting birds, and defend a territory during the breeding season. In West Asia, particularly in the Arabian Gulf Countries, larks breed in summer from March to June. Mostly, the female is the incubator and the male is the territory defender while both parents care for and feed the young (Cramp *et al.* 1988).

Birds in arid climatic areas are thought to have several physiological adaptations to their environments.

1.6.4 Distribution

The geographical range of species varies, e.g. the crested lark has a much wider range than the desert lark, and while the latter is strictly a desert species, crested larks inhabit both desert and non-desert regions (Shkedy & Safriel 1992 b). Even though both species share most seed types, they forage within the same habitat; crested larks have broader niches and higher temporal fluctuations in niche breadth than desert larks (Shkedy & Safriel 1992 a). However, the same bird species can show different distribution patterns according to local habitat structures and density of breeding individuals.

Once the breeding season begins, some lark species (e.g. greater hoopoe lark *Alaemon alaudipes Desfontaines*, crested lark) distribute in isolated pairs nesting in a territory area protected mainly by males. Song flight in the skylark is a noticeable feature during the breeding season. The skylark is one of the birds that uses song flight as a signal for mate choice and territory defence (Hedenstrom 1995).

Using the same macro or microhabitat by the same pair or male for several years depends on both species and habitat characteristics. The movements of Dupont's larks are over short distances; in most cases, they remain around their breeding sites during the non-breeding season, while part of the population moves some distance after breeding to lower sites and agrarian substrates (Suarez *et al*. 2006). To predict the distribution of species, a wide range of habitat information is required.

Typically crested larks are found in steppe, semi-desert and desert zones, especially low land plains and levels (Cramp 1988). Individual distribution pattern is a consequence of behavioural decisions. Many factors such as predator avoidance, shelter from weather and food quantity play a role in determining habitat preferences (Robinson & Sutherland 1999). The crested lark is not a markedly gregarious species and generally appears singly, in pairs or in small parties. However, large numbers may be attracted to favourable food or water supplies (Cramp 1988). Therefore, it is possible that the birds are not well adapted to being in groups and they may not incur the benefits, which could potentially make them more vulnerable to predators when they collect together in groups around environmental resources such as food, shade or water.

1.6.5 Feeding

Larks' diet changes from mainly granivorous in winter to mainly insectivorous in summer according to the available food in different seasons.

Larks may depend totally on insects, fruits or small seeds (Brown & Porembski 1997). Seed, fruits, maybe small grasses or leaves and insects comprise their main diet.

During May to July small grasshoppers formed the bulk of crested lark diets in Palestine, near Gaza (Hartley 1946). Crested larks posses a capacity to preserve food as body fat when it is abundantly available and become partially dependent on fat reserves in seasons when there is a scarcity or a shortage of food (Shkedy & Safriel 1991). Crested larks prefer to forage in high seed densities: they had much higher giving-up density than Allenby's gerbil *Gerbillus allenbyi* and greater Egyptian sand gerbil *Gerbillus pyramidum* when experimentally fed small cracked wheat (<1.4mm in diameter), medium (2.0-3.3mm) and large (> 3.4mm) seeds and used a fixed time for patch exploitation without being affected by seed sizes (Garb *et al.* 2000). They are more insectivorous than Allenby's gerbil *Gerbillus allenbyi* and Wanger's gerbil *Gerbillus dasyurus)* and their foraging ability did not vary much on sandy, cobble and loose substrates but they was most efficient forager on the last substrate (Kotler & Brown 1999). Crested larks are able to co-exist with gerbils and to feed on insects, fruit or smaller seeds in bush or open sand or rocky habitats (Brown & Porembski 1997). Little is known about sex differences but Moller (1985) found a difference between the number of steps taken between feeding stations among males and females when he studied feeding behaviour of crested larks in Alborg, Denmark.

Faecal pellets of skylarks throughout Western Europe showed that their winter diet was dominated by cereal grains (which are high in energy and highly profitable to feed on) and a few common weed species, while cereal leaves were prevalent in areas where seeds were scarce (Robinson 2004). However, horned larks feed more on male alkali bees than females where the estimated daily consumption ranges between 10 to 200 alkali bees and may eat an extra 300 to 1000 bees per day during nesting in central Nevada, USA (Rust 2003). Skylarks have been found to prefer to feed on crops such as wheat and sugar beet with high phosphorus and nitrogen contents (Green 1980). Natural high nitrogen contents of Medicago, a type of legume, make it preferable food for skylarks (Halse & Trevenen 1985). Rich nutrient contents (nitrogen and phosphate) are presumably correlated with high protein content (Green 1980, Diaz 1996, Diaz *et al.* 1996). Sugar beet is an important food source for protein, energy and necessary nutrient contents such as vitamin, iron, calcium and other minerals (Eslami *et al.* 1988). Grazing on crops of sugar beet provide high energy intake for skylark particularly in the breeding season (Green 1978).

1.6.6 Breeding

Most temperate zone passerines produce at least one clutch of eggs every year, whereas other small desert birds, such as greater hoopoe larks, may skip a breeding season in response to environmental factors (Tieleman *et al*. 2005). Summer breeding larks in low latitude regions, where the temperature is high and little food is available, demand high effort from parents during the incubation period. Reproduction and survival opportunity may be constrained by the amount of time, water and energy that parents can allocate to rearing offspring, e.g. greater hoopoe larks in Saudi Arabia were found feeding their offspring 55 times per day and shaded their chicks about 5 hours per day to protect them from solar radiation (Tieleman *et al*. 2003).

The nesting microhabitat of species varies with breeding region and seasonal conditions. The crested lark *Galerida cristata*, which breeds in the warmest months of the year, preferred artificial nest boxes provided in the most wind-protected locations on roofs (shelter and protection from South and southwestern direction in Hungary) and such areas are at same time also the driest (Orban 2004). The horned lark prefers a more northerly nest orientation, which offers multiple advantages for regulating the nest microclimate in northeastern California (Hartman & Oring 2003).

While horned larks nest in sparse cover and are relatively exposed (13% cover in midday), the lark bunting nests beneath shrubs, on the leeward side of shrubs, or on bunch grasses (40% covered in midday). As the Lark Bunting breeds later in the season than the horned lark, it is exposed to higher ambient temperatures and decreased winds. Male lark buntings assist the female with incubation, and its black plumage provides the opportunity for radiative cover (With & Webb 1993). An analysis of habitat characteristics in southwest Finland showed that wood larks select their breeding site carefully; their territories were found to be large and open, and 10-35% of suitable sites of rocky habitat types were vacant at any one time (Valkama & Lehikoinen 1994).

Crested larks are territorial in the breeding season; a male protects a territory and works as a sentinel while the female is incubating (Cramp *et al.* 1988). A study for 550 h in 1976-78 in Alborg Denmark reported that crested lark territories were 0.58 ± 0.16ha (N=21) and the population density of crested larks was 5.36-7.14 pairs/km^2 (Moller 1985). A crested lark male uses song flight as a signal for mate choice and territory defence as do many other song birds (e.g. Drury 1961, Verbeek 1967, Beason & Franks 1974, Wunderle 1978, Greig-Smith 1982, Hedenstrom 1995). In Alborg Denmark, Moller found 32% of 62 crested lark nests were placed within vegetation and 68% were among stones, tree boxes, etc (Moller 1985).

1.7 Specific Research Objectives

In this thesis I addressed two main questions. The first, and the most important, was to examine the extent to which the current conservation measures in Kuwait actually influence biodiversity. I addressed this at two levels – plants and birds. I looked at species richness and at density. My hypothesis was that in the protected areas biodiversity and abundance would be greater for both. This was the case. Simple measures of abundance can however be misleading. I also needed information on the fitness of animals in the different habitats because high density areas may contain poorer quality individuals excluded from the best areas (Johnson 2007). Ideally, I should look at breeding success, longevity, condition. I could not do this. I did look at distribution of bird nests. To give an indication of habitat quality and breeding suitability. My hypothesis was that there would be more nests in the protected areas. This was so. I also looked at the farmland, which could be high quality breeding habitat but nests are destroyed by harvesting. Breeding success was much more difficult to quantify. However, it was clear that while there were a high number of nests of crested larks in the farmland area that I studied, they were destroyed at harvesting.

1.8 Study area

My study area was located in open and protected areas in north and west of Kuwait during 2008-09. Selected areas were two protected areas Sabah Al-Ahmed Natural Reserve (SAANR), 330km^2 and Kabd Scientific Research Station (Kabd), 40km^2 and two unprotected areas of similar landscape (behind Sabah Al-Ahmed Natural Reserve (B-SAANR), 80km^2 and a right-hand area adjacent to Kabd Scientific Research Station (R-Kabd), 40km^2 (Figure 1.17). The general landscape was characterized by short sparse bushy and grassy desert plants. Grazing, hunting and camping are forbidden in the protected areas whereas they are permitted in unprotected ones. I also sampled an agricultural area, the Pivot farm (Pivot), 8 km^2. The Pivot farmland contains 19 irrigated circular crops varying in radius 0.5-0.9km, used mainly to grow seasonal leafy and cereal crops (foliage 80%, barley 10%, maize 10%). The pivot owner's camel and sheep herds graze continuously in the farmland.

More detailed methodological descriptions are given in each Chapter. Each chapter is presented as an independent section in the format of a manuscript, in line with current practice at the Institute of Biodiversity and Animal Health University of Glasgow.

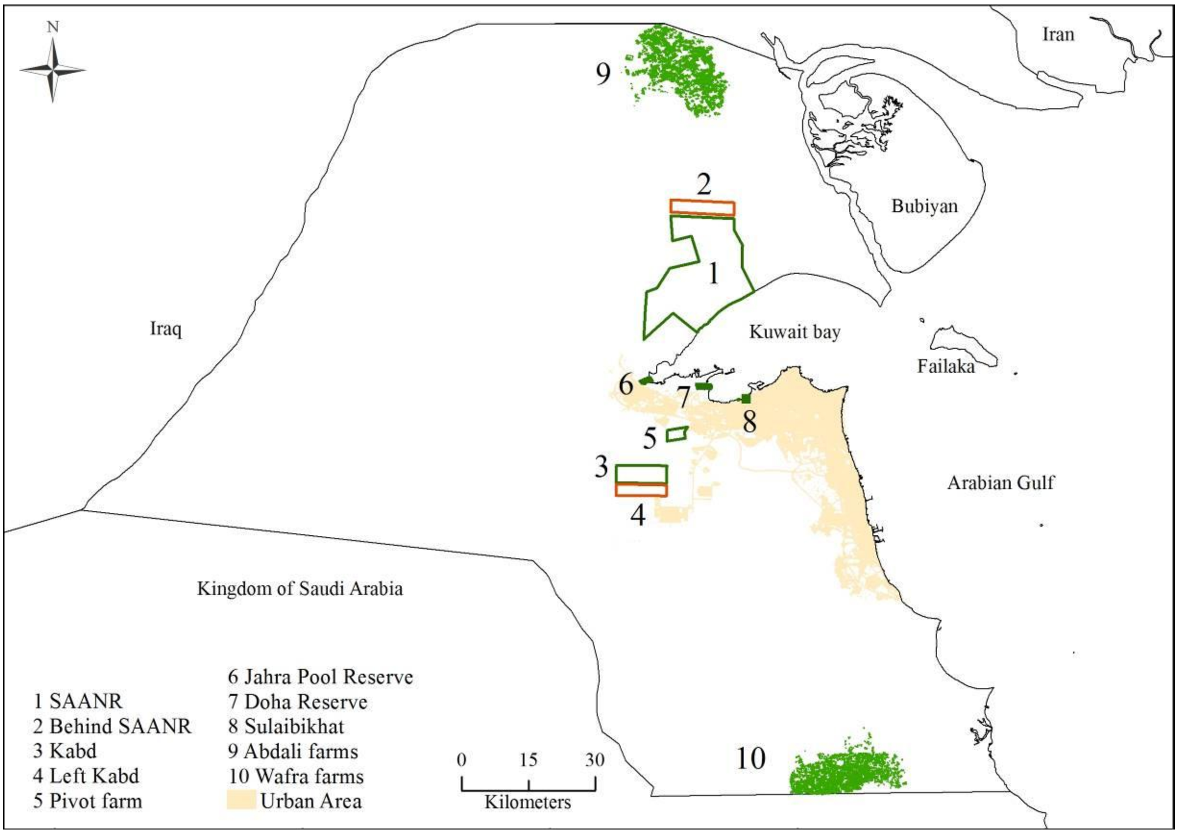


Figure 1.17 Kuwait Map; 1 SAANR PA, 2 Behind SAANR NPA, 3 Kabd PA, 4 Left Kabd, 5 Pivot farm (Google Earth 2009).

My second question was concerned with how birds cope with the thermal challenge posed by such as hot and arid environment as is found in Kuwait. I first tried to quantify what the challenge was by examining temperature fluctuations in a range of real and artificial nests. It was substantial in high summer. Secondly, I looked to adaptations of the eggs. My hypothesis was that the eggs of Kuwait birds would be more resistant to water loss that related (or the same) species in temperate areas. I found this not to be the case. I quantified the thermal challenge in nest position by using data loggers to record temperature. This helps explain choice of habitats and timing of breeding since the challenge is reduced in vegetation and early in the season. Nest position also matters. Habitat matters too- nests in the farm where is wetter are cooler.

I also looked at water loss and shell colouration. I did these measurements between sibling species and also the same species in different areas. Surprisingly, the desert species lose more water through their shells. The results were puzzling, but other factors may be important and respiratory water might also differ. Also, the presence of the parent will make a big difference to water loss.

I carried out some additional studies of the use, predation risk and behaviour at water holes. Water is extremely important in this arid environment. Many species collect around water holes outside of the breeding periods. Density is high, and there are predators too. I quantified variations in abundance. For the behavioural work, my hypothesis was that the birds would show behavioural modifications (group size, vigilance behaviour) that help offset these risks.

Chapter 2: Habitat Structure and Plant Diversity

Abstract

An assessment of the vegetation in the semi-arid desert habitats of Kuwait was carried out in January 2009. This part of my study aimed to identify the plant species present and to quantify habitat types in protected and open (non-protected) areas in Kuwait. I examined the relationships between human activity factors (e.g. grazing, camping, etc) and vegetation richness in North and West Kuwait.

The survey covered two protected areas (SAANR, Kabd) and two comparable areas (Behind SAANR, Right Kabd). The vegetation was sampled by placing 84 transects at random locations along roads in the study area. For each transect 4 - 5 quadrats (1 x 1 m) were laid out randomly (previously acquired by using a generation of random sampling in excel program) along a transect distance of 5 – 25 m from either the left or right hand side of the road, giving a total of 420 quadrats. Soil texture and vegetation data including density and cover percentage were estimated quantitatively within each quadrat.

The data were classified using Two-Way Indicator Species Analysis (TWINSPAN) to divide the samples into three sample-groups of high internal similarity in terms of plant species presence. Total plant species richness was 20, 35, 2 and 17 species per area in SAANR, Kabd, Behind SAANR and Right Kabd respectively. Open areas showed very limited species occurrence, and low vegetation cover as expected. The vegetation cover varied significantly with location, soil, grazing and camping. In comparison to protected land, grasses, forbs and shrubs were highly reduced in open grazed land.

The frequency of palatable species of grasses and forbs (for grazing animals) was higher in the protected rangeland. In all sites, perennial plants were dry and in bad condition due to rain shortage. In both open rangelands, plant cover was lower and the vegetation height was shorter than in protected rangelands. Habitat conditions were very impoverished in Behind SAANR, with 99% of samples supporting only one plant species.

In total 46 plant species were identified, forming three recognizable vegetation types (labeled A, B and C), which could be identified as belonging to three of the five known main plant communities of the study area. The vegetation types present were a *Haloxylon* community (C); a sub-community (B: indicated by *Helianthemum*) of the *Stipa* community type; and a sub-community (A: indicated by *Plantago* and *Schismus*) of the mixed *Stipa* - *Cyperus* community type. There was little evidence to suggest the presence of the two remaining known plant communities of this area within the areas sampled (these being a *Rhanterium* community and a *Stipa* community type). The densest populations were of *Stipa* followed by *Haloxylon*. The most frequent species was *Plantago,* which was present in most habitats in transects comprising sample-group A. The low plant diversity in the unprotected open rangelands demonstrates the need for a new strategy to rehabilitate ecological habitats.

2.1 Introduction

Plant cover isstrongly influenced by geomorphologic characteristics and the soil and climate of a region. Kuwait is mostly a flat sandy land characterized by four ecological systems: 1) Sand dune ecosystem; 2) Coastal plain and lowland ecosystem; 3) Desert plain ecosystem; and 4) Desert plateau ecosystem (El-Shora & Jasim 1996).

In this study, vegetation was sampled in the desert plain ecosystem. It occupies the greater part of the country and contains three main communities; *a)Cyperus* steppe, *b)Rhanterium* steppe and *c)Haloxylon* steppe (Halwagy & Halwagy 1974).

The vegetation is categorized by a few grasses and herbs, and short scattered shrubs. Halwagy and Halwagy (1974) described the vegetation of Kuwait "as a poor open scrub of under-shrubs, perennial herbs and ephemerals". They also added that tall shrubs are restricted to favourable sites only and growing to ‘about a man’s height’.

Previous studies on the flora of Kuwait have revealed 374 native and naturalized plant species in 55 families, of which 256 species (68.4%) are annuals, 34 species (9.1%) are shrub and under-shrubs and only one species (0.3%) was a tree, whereas herbaceous perennials represented 83 species (22.2%) of the flora (Boulos & Al-Dosari 1994). Dickson (1955) classified Kuwait vegetation cover into four plant communities: 1)*Haloxylon*; 2)*Rhanterium*; 3)*Cyperus* and 4)*Panicum*. Subsequently, five plant communities were recognized in Kuwait State (Kernick 1966, Halwagy & Halwagy 1974) see (Figure 2.1). Recently, Omar *et al.* (2001) defined eight dominant plant communities: 1)Haloxyletum; 2)Rhanterietum; 3)Cyperetum; 4)Panicetum; 5)Stipagrostietum; 6)Zygophylletum; 7)Centropodietum; and 8)Halophyletum by integrating soil and vegetation information using a Geographical Informational System (GIS) (see Figure 1.12). They ascribed this alteration in dominant plant communities over a few decades to both natural and human factors. The original dominant plant species are being replaced by a secondary dominant plant species due to overgrazing, quarrying or other ecological disturbances (Omar *et al*. 2000).

Distribution and abundance of dominant perennial shrubs have declined, being replaced by grassy and annual plants, or spiny species (Halwagy & Halwagy 1974, Omar *et al*. 2000). A range land in Kuwait will reach the climax ecosystem when it is mostly occupied by *Rhanterum epapposum* or *Haloxylon salicornicum* perennial species (both are woody shrubs). It is likely to be in moderate condition when *Cyperus conglomeratus* (short thin grassy perennial plant and somewhat palatable to cattle) dominates, and in bad condition when *Cornulaca* (very spiny leafless species) and/or annual forbs increase, before the worst conditions of bare ground status are reached (Omar *et al.* 2000).

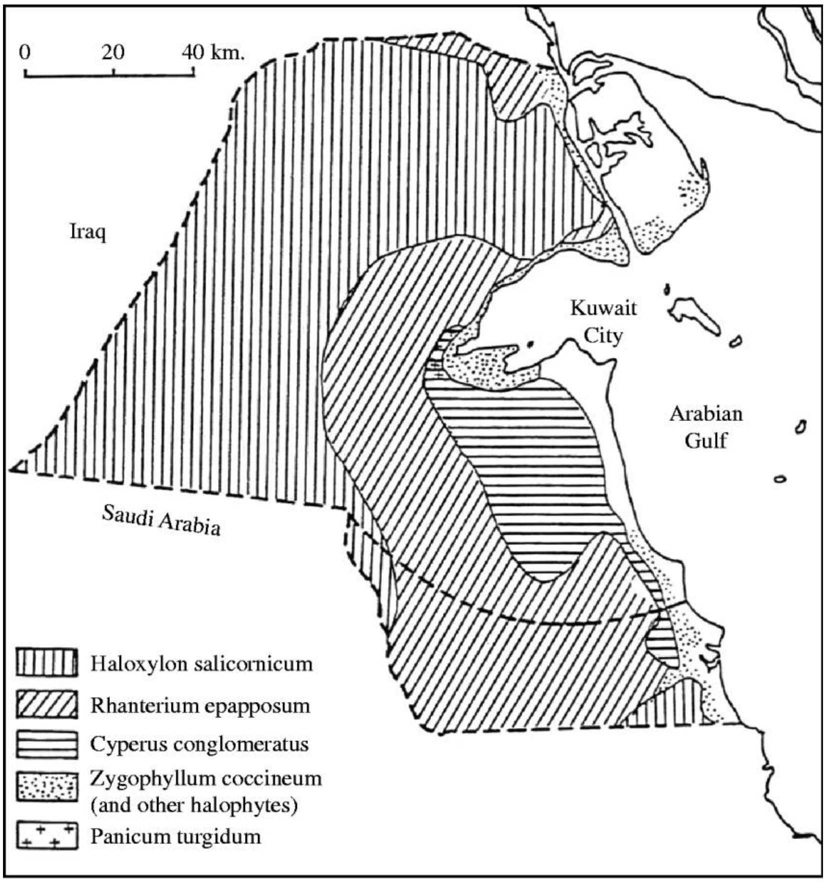


Figure 2.1 Plant Map of Kuwait State (Halwagy & Halwagy 1974)

Silviculture along roads, avenues, roundabouts and parks cover about 43km^2 and about 648520 trees. Farm lands covered about 24,000 hectares, from which 5,000 hectares are planted and distributed into three areas: 1)Wafra 370 farms, 2)Abdali 156 farms, and 3)Sulibia 33 farms mainly for cattle and sheep breeding (Environmental Public Authority 2003).

In Kuwait, natural vegetation cover was seriously degraded in large areas of desert habitats by the early 1990s (Khalaf & Al-Ajmi 1993) and became an indicator of land degradation (Al-Awadhi *et al.* 2003). Natural vegetation covers less than 10% of many land areas in Kuwait (Al-Awadhi *et* *al.* 2003).Intensive human activities combined with fragile ecological conditions in Kuwait accelerated environmental degradation by which annual land desertification is approximately 285 km^2 per year (Al-Awadhi *et al.* 2003) and average width of annual sand drift rate is $20m^3$ (Khalaf & Al-Ajmi 1993).

El-Sheikh and Abbadi (2004) found 139 plant species belonging to 32 families in SAANR. SAANR includes rare and endangered plant species (Daoud & Al-Rawi 1985, Bolous & Al-Dosari 1994, El-Sheikh & Abbadi 2004). In addition, it includes one individual of *Acacia pachyceras* which is the only tree species occurring in Kuwait until 85 years ago (Omar *et al*. 2005).

In a pilot survey, which was carried out in 2008, I found that the majority of farmland areas in Kuwait were small. In the Wafra region, farms vary in their areas from 7.5 to 25 hectares whereas in Abdali region farms vary from 15 to 25 hectares. In addition, most farms were fragmented for planting of different crops (e.g. closed protected crops such as vegetable marrow/courgette, cucumber or tomato). Hence, the small area of those farms are unsuitable habitats for ground foraging and nesting species such as larks *Alaudidae* due to the limited open shrub or short crop spaces. Accordingly, I chose one large farm (800 hectares) growing alfalfa and barley crops on a large scale, which attracted numerous species of birds. This farm was named locally ‘The Pivot Farm’ due to the shape of the crop areas, which are sown in circles and watered by an automotive irrigator arms' system. These crops in the Pivot created a semi-natural grass habitat for larks. Large numbers of crested Larks and Skylarks where seen foraging in alfalfa crops and in it borders.

In this part of my study I aimed to do the following: 1) identify the richness of plant species in protected and non-protected areas and in farmland 2) quantify the habitat quality of protected and non-protected areas, and in farmland. 3) evaluate the effect of human activity factors (e.g. grazing, camping, etc) on habitat ecology and its vegetation richness. Later in this thesis I will use these measurements to examine the consequence of habitat quality on bird abundance and distribution in Kuwait.

2.2 Methods

Study area and sites

The study sites were located in protected and non-protected areas in North and West Kuwait and surveyed during 2008-09. Two protected areas were selected: Sabah Al-Ahmed Natural Reserve (SAANR: 330 km^2 in the North), and Kabd Scientific Research Station (Kabd: 40 km^2 in the West); similar adjacent open, unprotected areas, labeled "Behind Sabah Al-Ahmed Natural Reserve (B-SAANR: 80 km^2), "Right Kabd Scientific Research Station" (R-Kabd: 40 km^2); and the agricultural area, Pivot farm (Pivot: 8 km^2) were studied for comparison with the protected areas (see Figure 2.2).

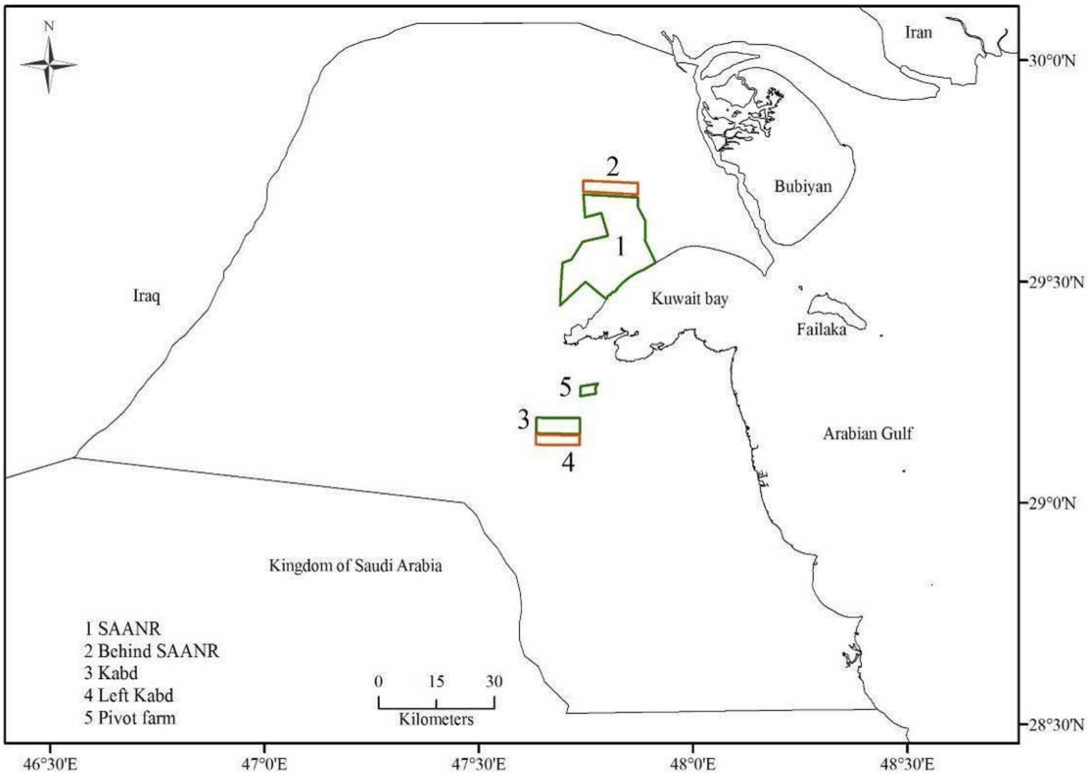


Figure 2.2 Kuwait Map; 1: SAANR PA, 2: Behind SAANR NPA, 3: Kabd PA, 4: Right Kabd, 5: Pivot farm

The unprotected lands are used as rangeland areas; B-SAANR and R-Kabd were both characterized by sparse bushy and grassy desert plants. The Pivot is a farm where agricultural crops (such as trefoil, barley and corn) are planted. Grazing, hunting and camping are forbidden in the protected areas but permitted in unprotected ones. In the Pivot, hunting and grazing is under control of the owner. Hence, it can be considered as a semi-protected area (an intermediate between open and protected areas)

The vegetation was sampled by identifying 84 transects at random locations along roads in the study area. Random numbers (5 – 25 m left or right hand) were previously acquired by using a generation of random sampling in excel program. For each transect 5 quadrats (1 x 1 m) were laid out along a transect distance of 5 – 25 m from either the left or right hand side of the road, 105 quadrats in each area giving a total of 420 quadrats (Figure 2.3 and 2.4).

Figure 2.3 Existing roads were used to sample vegetation in each surveyed area(SAANR PA, Behind SAANR NPA, Kabd PA, Right Kabd NPA). The figure illustrates that the areas thin 5-25m of the roads are representative of the overall vegetation in the area.

Figure 2.4 A quadrat 1x1m^2 was used on right hand or left hand of existed roads according to random numbers between 5 to 25 meters which were acquired by using generation of random sampling option in the excel program.

This distance was chosen to ensure that the area surveyed was comparable to the area in which birds were censused. Soil texture and vegetation data including density and percentage cover were estimated quantitatively within each quadrat.

In Pivot farm, transect sampling was not undertaken for logistic reasons, but crop types were identified in every sector. The area of each sector was measured. Then, the total percentage cover of each crop was computed for the whole area of the farm.

Statistical analysis

Species percentage frequency of occurrence within the 5 quadrats making up each transect sample was calculated. Percentage frequency of plant species per transect sample was thus as follows: zero (not present in any one out of five quadrats), 20% (present in one out of five quadrats), 40% (present in two out of five quadrats), 60% (present in three out of five quadrats), 80% (present in four out of five quadrats) and 100% (present in all five quadrats).

Two-way indicator species analysis (TWINSPAN for Windows 2.3) was used to classify the 84 transect samples. Cut-off levels for the analysis were selected to give 4 pseudospecies: 1(<20%F), 2 (<40%F), 3 (<60%F) and 4 (≥60%F). Otherwise a default analysis was selected.

2.3 Results

In total, 46 plant species and 20 families were identified from the transect sample sites within the study areas. Total plant species richness was 20, 35, 2 and 17 species in SAANR, Kabd, Behind-SAANR and Right-Kabd respectively. Unprotected areas showed very limited species and low vegetation cover, as expected (Figure 2.5 and 2.6).

Figure 2.5 Habitats of non-protected areas B-SAANR and R-Kabd. Off-road trucks, camping and grazing in non-protected areas consumed and destroyed most vegetation cover. Upper two photos show the trace of offroad trucks and grazing. Lower two photos show the difference between vegetation cover in Kabd protected area behind the fence and outside as a consequence of uncontrolled human activities.

Figure 2.6 Vegetation sampling in non-protected areas B-SAANR and R-Kabd. Off-road trucks and grazing is a remarkable sign in most lands of non-protected areas. Upper two photos show the trace of offroad trucks and grazing in the quadrat. Lower two photos show only roots of Halyxonuim shrubs and absence of green vegetation cover in B-SAANR.

Diversity of plant species was very low in non-protected areas in comparison to protected areas (Figure 2.7). Compositae and Leguminosae formed the most common families in the studied areas. The former contained 10 (21.7%) of all plant species while the latter contained 5 (10.9%) of plant species.

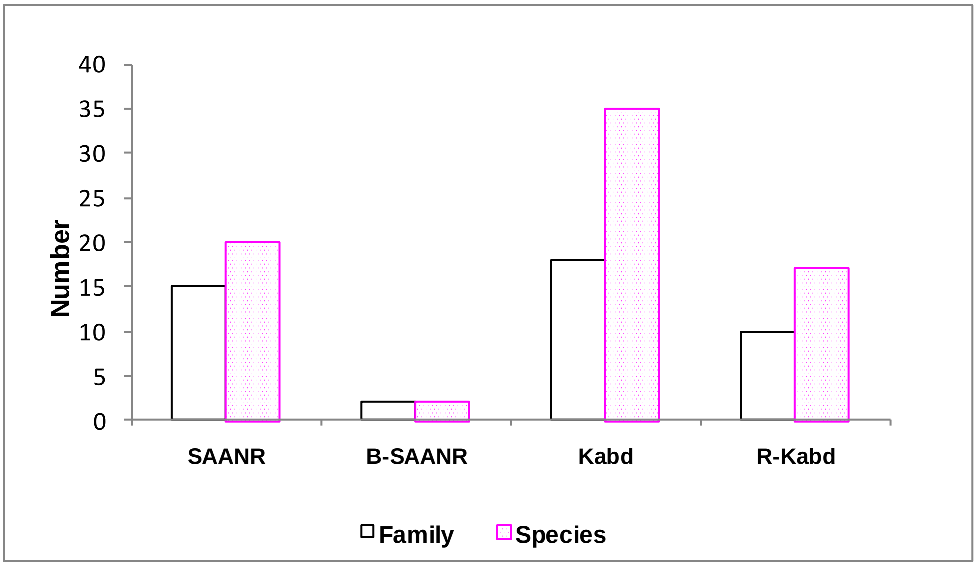


Figure 2.7 Plant species diversity in unprotected and protected areas. Species and families represent the total number which were seen within 105 quadrats randomly chosen in each area. Richness of families and species were markedly difference between protected areas and non-protected areas. SAANR protected area showed richness of species and families more than10 times B- SAANR non-protected area. Also, species and families ricness in Kabd protected area were twice richness of R-Kabd non-protected area.

Mostly open areas lacked perennial species and shrub forms. Absence of shrubs and very poor vegetation cover was a notable feature in both open areas. Shrubs or annual herbaceous plants were very rare in open areas and restricted to within a few meters of localized areas or patches (a few meters in extent) due to presence of fences or mound barriers belonging to recreation camping or road barriers where vehicle or grazing is impossible or difficult. In most cases, areas surrounding these small patches of localized vegetation growth were totally bare. R-Kabd was totally devoid of shrubs while B-SAANR contained only one type of shrub, *Haloxylon salicornicum* (Figure 2.8).

The presence of *Cornulaca aucheri* (a spiny unpalatable plant species) in R-Kabd (open area) was an indicator of its poor range land habitat. The most encountered species in R-Kabd were common annual species which have a short lifespan and they did not form a stable community.

Protected areas were characterized by the presence of stable habitat communities such as Haloxyletum (*Haloxylon salicornicum*) and Stipagrostietum (*Stipagrostis plumosa*). Also, tree species *Lycium shawii* and a shrub species *Rhanterium epapposum* were only seen in protected areas. The former was seen in SAANR while the latter was seen in Kabd. Furthermore, five rare species: *Helianthemum kahiricum*, *Gagea reticulata*, *Allium sindjarensis. Rhanterium epapposum*, *Sclerocephalus* and *arabicus* were seen in protected areas but absent from open areas. *Rhanterium epapposum* was a rare shrub species in open areas and its distribution low.

In addition to rare species, some species of medical significance were identified that have importance for a habitat for scientific and/or economic purposes (Abbas & Alsaleh 2002). SAANR and Kabd protected areas both together included 11 medically useful species: *Haloxylon salicornicum, Fagonia bruguieri, Lycium shawii, Plantago boissieri, Moltikiopsis ciliate, Emex spinosa, Rumex vesicarius, Malva parviflora, Neurada procumbense, Koelpinia linearis, Cressa cretica.* Three of these species were seen in open areas: *Haloxylon salicornicuma, Plantago boissieri, Moltikiopsis ciliate* but with less frequent/abundance and stunted.

A grass species, *Stipagrostis plumosa*, was the only common species that was present in all the studied areas. It was present in open and protected areas and in the Pivot farm.

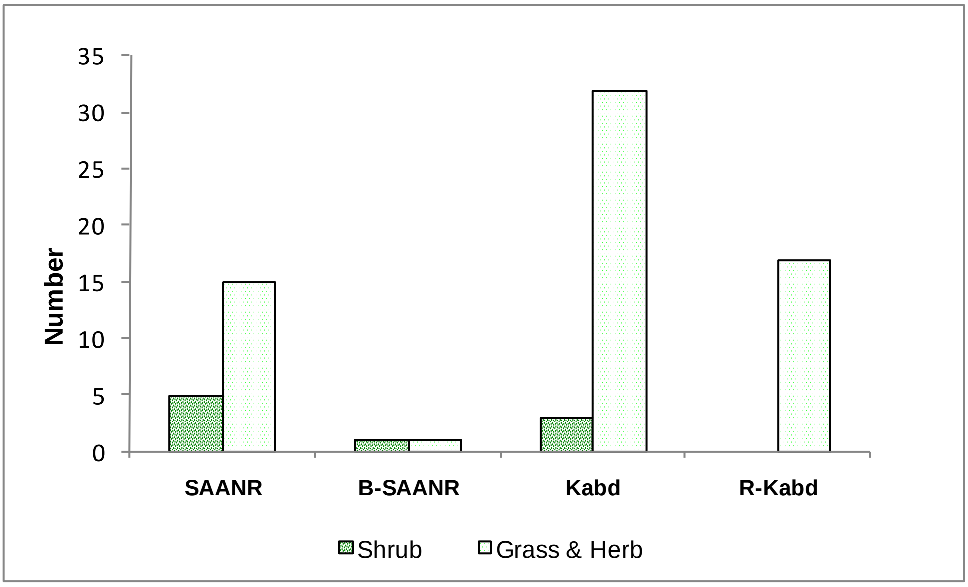


Figure 2.8 The number of species of shrubs and of grass and herbs in unprotected and protected areas. Shrub and grass & herb species represent the total number which were seen within 105 quadrats randomly chosen in each area. Richness of shrub and grass & herb species was markedly different between Protected areas and non-protected areas. Shrub species in SAANR protected area were 5 times B-SAANR non-protected area. In R-Kabd non-protected area, shrub species were absence. Grass and herb in SAANR protected area. .

However, *Haloxylon salicornicum*, which was almost the only plant species observed in B-SAANR (open area), was in a very bad condition with mainly leafless stems, and showing clear signs of disturbance damage. In part this would be due to normal winter dieback of the plant but much of the damage can be attributed to human disturbance (camping and vehicle damage), and grazing in the open, unprotected area

Absence of annual species in B-SAANR reflects the status of the soil in this habitat (Figure 2.9). Its soil is very compacted and not suitable for annual species to grow in.

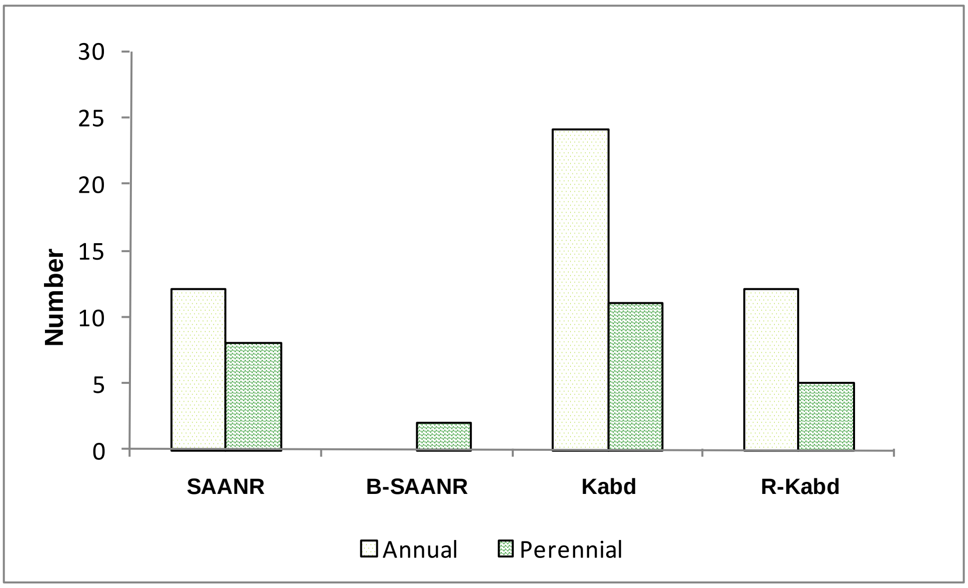


Figure 2.9 Number of annual and perennial plant species recorded in unprotected and protected areas. Annual and perennial species represent the total number which were seen within 105 quadrats randomly chosen in each area. Annual and perennial species dicersity was remarkable different between protected areas and non-protected areas. Annual species richness in SAANR and Kabd protected areas were 12 and 2 times higher B-SAANR and R-Kabd non-protected areas respectively. Perennial species richness in SAANR and Kabd protected areas were 4 and 2 times higher B-SAANR and R-Kabd non-protected areas respectively. B-SAANR was the worest area withno annual plant species and only two perennial plant species. Most perennial plant species were grazed or in bad condition and offroad trucks prevented growth of annual plant species.

Plant cover was 10.2% and 23.9% in SAANR and Kabd compared with 0.8% and 3.4% in B-SAANR and R-Kabd respectively. Plant species diversity per quadrat was with an average of 2, 0, 5 and 1in SAANR, B-SAANR, Kabd and R-Kabd respectively. Average number of individual plants in a quadrat within protected areas SAANR and Kabd were 5 ±1 and 38±5 respectively compared within non protected areas B-SAANR and R-Kabd were 1±0.1 and 3±1 individuals respectively. One way ANOVA test showed a significant difference in number of individual plants in a quadrat within these sites: P value <0.0001, F= 68.51, df= 3.

Height of vegetation was significantly different between open areas and protected areas. It was very short in both open areas B-SAANR (3.4±0.6 cm) and R-Kabd (1.5±0.4 cm) in comparison with protected areas SAANR

(12.3±1 cm) and Kabd (20±2.2 cm). One way ANOVA test showed a significant difference in hight of plants within these sites: P value <0.0001, F= 36.69, df= 3.

In Pivot farm, crop types were identified in every sector. The area of each sector was measured. Then, the total percentage cover of each crop was computed for the whole area of the farm (Figure 2.10).

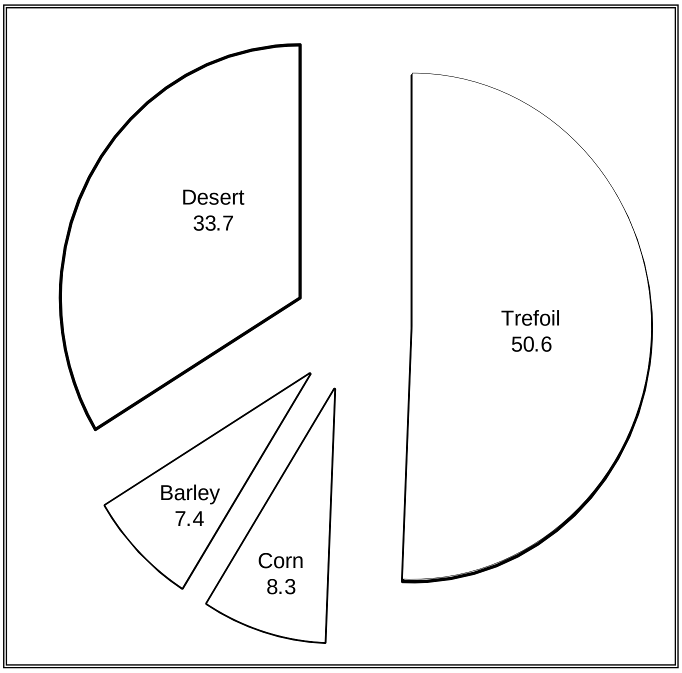


Figure 2.10 Percentages of occupied habitats Pivot farm (area in hectares)

Classifying the sites using TWINSPAN (Figure 2.11 and Appendix 1) produced three main sample-groups: labelled A, B and C, and colour coded blue (C), yellow (B) and green (A) (see Figure 2.7 and Appendix 1).

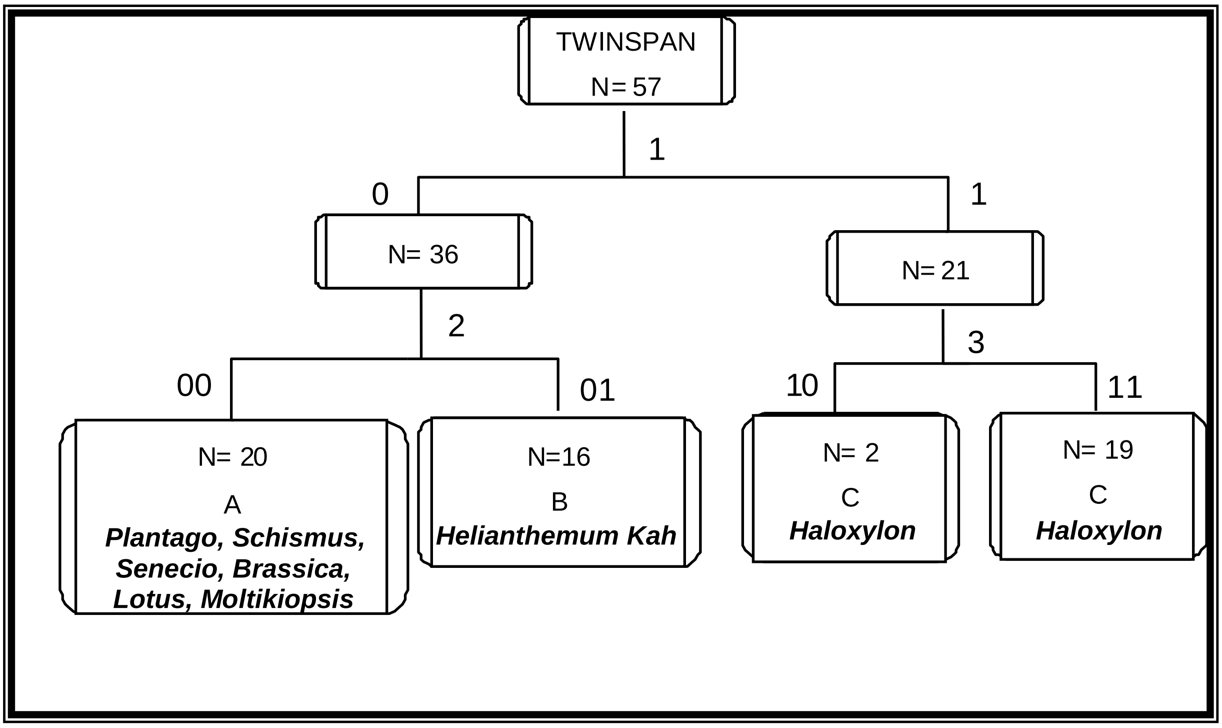


Figure 2.11 TWINSPAN sample end -groups A – C for the dataset, showing indicator species for each group in bold (see Appendix 1).

Group C (n = 21 transect samples) was strongly separated from the remainder of the data set at the first hierarchical division (eigenvalue: 0. 858), and supported a very species-poor flora, with a maximum of 4 species in two of the samples, and only 1 species (the indicator for the sample-group: *Haloxylon*) at nearly all the rest. The majority of the samples were from B-SAAN (unprotected), but three were from within the nearby protected SAAN area. This sample group clearly closely corresponds to the *Haloxylon* plant community known to exist in the area, and appears to be characteristic of heavily disturbed open rangeland vegetation.

Groups A (n= 20 transect samples) and B (n= 16 transect samples) separated at the second level of the classification hierarchy, again with a high eigenvalue (0.618) for the division, suggesting a clear separation of the vegetation types represented in samples present in the two groups (though with more overlap of species than for the first division, which produced group A).

Group B had a diversity intermediate between A and C, and was indicated by *Helianthemum*, which was present at moderate to high abundance in all but one of the transect samples comprising the sample-group. Since *Stipa* was present at high abundance in about half the transects making up this group, but *Cyperus* was completely absent, it is likely that this sample group represents a sub-community of the known *Stipa* plant community present in the region. All samples in this group were from the protected SAANR area

Group A had by far the highest plant diversity, and supported a large number of species not found in transects comprising groups B or C (Figure 2.7). It was indicated by the abundant presence of *Plantago*, together with *Schismus*: both plant species were uncommon or absent at sites making up the other sample-groups. Either one or both of *Cyperus* and *Stipa* were usually present in the transects comprising group A, so it is probable that these samples represent a sub-community of the known *Stipa* – *Cyperus* plant community present in the area. Samples were all from protected areas, comprising all of the Kabd transects and a number of those collected from SAANR.

Table 2.1 summarises species occurrence in the studied areas. The densest populations were of *Stipa* followed by *Haloxylon*. The most frequent species was *Plantago*, which was present in most habitats in group A transects.

The vegetation cover significantly varied due to location, soil, grazing and camping. In comparison to protected land, grasses, forbs and shrubs were highly reduced in open grazing land.

The frequency of palatable species of grasses and forbs was higher in the protected rangeland. In all sites, perennial plant condition was dry and in poor condition due to lack of rainfall. In both open rangelands, plant cover was lower and shorter than protected rangelands. Habitat condition was very severe in Behind SAANR, with 99% of samples supporting only one plant species.

The Pivot farmland contains 19 pivot-irrigated areas varying in radius between 0.5 - 0.9 km, and used mainly to grow seasonal leafy and cereal crops (alfalfa 80%, barley 10%, maize 10%). The farm owner’s camel and sheep herds graze daily in the farmland.

Table 2.1 Diversity of flora in studied areas

N	Species name	SAANR	B-SAANR	Kabd	R-Kabd
1	*Haloxylon salicornicum*	+	+		
2	*Helianthemum kahiricum*	+			
3	*Stipagrostis plumosa*	+	+	+	+
4	*Cyperus conglomeratus*			+	+
5	*Fagonia bruguieri*	+		+	
6	*Lycium shawii*	+			
7	*Plantago boissieri*	+		+	+
8	*Astragalus annularis*	+		+	+
9	*Launaea capitata*	+			
10	*Launaea mucronata.*	+			
11	*Moltikiopsis ciliata*	+		+	+
12	*Arnebia decumbens*	+		+	+
13	*Ifloga spicata*	+		+	+
14	*Gagea reticulata*			+	
15	*Allium sindjarensis.*	+		+	
16	*Astragalus spinosus*	+			
17	*Astragalus corrugatus*	+		+	
18	*Emex spinosa*	+			
19	*Rumex vesicarius*			+	
20	*Malva parviflora*	+		+	
21	*Neurada procumbense*	+		+	+
22	*Schismus barbatus*	+		+	+
23	*Aeluropus littoralis*				+
24	*Rhanterium epapposum*			+	
25	*Picris babylonica*			+	
26	*Senecio glaucus*			+	
27	*Lotus halophilus*			+	+
28	*Gymnarrhena micrantha*				+
29	*Carduus pycnocephalus*			+	+
30	*Koelpinia linearis*			+	
31	*Reseda muricata*			+	
32	*Gynandrisis sisyrinchium*			+	+
33	*Brassica tournefortii*			+	+
34	*Trigonella anguina*			+	
35	*Salsola imbricata*			+	
36	*Savignya parviflora*			+	
37	*Cornulaca aucheri*				+
38	*Scabiosa olivieri*			+	
39	*Cakile arabica*			+	
40	*Lappula spinocarpos*			+	+
41	*Cressa cretica*			+	
42	*Calendula arvensis*			+	
43	*Sclerocephalus arabicus*	+			
44	*Crucianella membranacea*			+	
45	*Astragalus hauarensis*			+	
46	*Asphodelus tenuifolius*			+	

2.4 Discussion

Floral richness in the study areas was less than expected based on previous studies (Boulos & Al-Dosari 1994 and Omar *et al* 2005). However, species richness in Kuwait may fluctuate significantly from year to year as in other desert lands. In desert ecology, meteorological variables, especially the amount and time of rainfall, triggers germination of annual species (Went 1955, Bowers 1987). Most plants in Kuwait are annual species. Consequently, they are extremely influenced by rainfall. Average rainfall was very low 75mm and 50mm in 2007 and 2008 respectively (Figure 1.5 Annual rainfall in Kuwait State, page 20). Consequently, low average rainfall influenced the floral richness and coverage. Furthermore, my sampling was conducted in the early season prior to climax growth of vegetation. In the other studies, sampling was conducted about one month later during climax growth of vegetation.

It is clear from my results that floral richness can be used as an indicator of healthy habitats. This is consistent with Kassas and Imam's (1954) results from Wadi-bed ecosystem in Egyptian desert. They demonstrated that plants are the best indicators of the habitat conditions, especially dominant plant species (perennial species in case of desert habitats). My results confirm the findings of Al-Awadi *et al*. (2003) that vegetation can be used as an indicator of land degradation. Richness of species can be used as an indicator of ecosystem status whereas abundance of species and its percentage cover can be used as an indicator of landscape disturbance/fragmentation or succession (Dale & Beyeler 2001). It would be useful if indicators represented site-specific conditions which described the ecosystem, based on scientific knowledge and are simple to monitor periodically (Cousins & Lindborg 2004). Absence of *Rhanterium epapposum* or decline of its percentage cover in the historical distribution of this species is a scientific indicator of land degradation in Kuwait. *Rhanterium epapposum* and *Haloxylon salicornicum* are very important dwarf shrubs to stabilize Kuwait ecosystem by depositing windblown sand and promote species diversity (Brown & Porembski 1997).

Omar *et al*. (2005) categorized the *Rhanterium epapposum* community as a sign of a climax community (that forms the best grazing land) in the Kuwait desert plain ecosystem. My results showed a remarkable succession of range land in open areas: B-SAANR and R-Kabd. Rare and palatable plant species are facing a very high threat of extinction in open areas due to land degradation. In this study *Rhanterium epapposum* was absent in SAANR which matched with the findings of El-Sheikh and Abbadi (2004), although this species is recorded in the SAANR area (see Figure 2.1). The presence of *Rhanterium epapposum* in Kabd was very small and restricted to limited localized areas. This coincides with the results of Brown (2003) who found its cover to be less than 2%.

Overgrazing depletes the potential ability of habitats to renew their vegetation. Furthermore, off road tracks destroy large areas of open range lands and compact the soil or make it too loosely based on soil texture and features. Hence, seeds will not able to grow up due to compacted or unstable soils. In B-SAANR, annual plants were totally absent due to compacted soils as a result of long use of land. On the other hand, R-Kabd has more annual plants than B-SAANR. Soil nature is assumed to play a role in this difference. Loose texture of R-Kabd and presence of some recreation camping fences give better chance for annual plants to grow, while the compacted gravel soil texture of B-SAANR makes it hard for these plants to germinate and grow. Brown and Schoknecht (2001) found that the moderate disturbance caused by the single passage of a vehicle could result in a slightly elevated species diversity, but this finding was restricted to very loose sand and cannot be generalized for all habitat areas.

However, plant species in R-Kabd were limited and did not offer a stable micro habitat rather than macro habitats. It is difficult to find non-grazed or healthy plant communities. An over grazing effect was obvious on vegetation and its species diversity. Open areas were characterized by short height, less vegetation cover and less plant species in comparison to protected areas. Uncontrolled public activities such as recreational camping, riding buggies and four wheel vehicles everywhere in open land add to the negative effects of overgrazing in degrading Kuwait habitats dramatically.

2.5 Conclusion

Vegetation is a powerful indicator of land degradation in Kuwait. Richness of plant species was correlated negatively with land degradation. Flora families and species in protected areas were between 2 and 10 times that of open areas. The richest open area (R-Kabd) maintained half the flora species richness compared with (Kabd) protected areas, whereas the worst open area (B-SAANR) showed one-tenth of flora species richness in (SAANR) protected area. This remarkable variance shows the important role of protected areas.

Significant difference of vegetation cover and its component species between protected and unprotected areas require decision makers to develop a national strategy to preserve ecosystems. Open areas need some powerful regulations to reduce their degradation. Legislation regulating of camping, grazing and other human activities should be revised and enforced to conserve open access areas. Hence, premature death of plant species will reduce their individual numbers and their chance to appear in consequence years (Brown 2001). Extensive degradation will need prolonged and intensive remediation especially in dry environments and shallow soils (Brown 2003). Consequently, desertification is irreversible without replanting even after 25 years of total protection (Le HoueHrou 1996). Open rangelands demand a new strategy to rehabilitate ecological habitats.

The quality of vegetation cover and flora richness in protected, non protected and the Pivot farm will be used to assess their effects on birds diversity and distribution (in chapter 3). Also, these areas will be evaluated in response to preferred breeding habitats of larks (in Chapter 5).

Chapter 3: Bird Density and Abundance

Abstract

Protected areas are generally designed with the aim of providing improved habitat for species that live and breed in them. The aim of this study was to examine the extent to which habitat protection is influencing the Kuwait avifauna, and to assess the conservation benefits. Using the lark species as a measurable indicator of this, I compared species richness and density between protected and non-protected areas. I found significant differences between lark density and species richness in protected, non-protected and arable lands. Density of larks was very low in non-protected areas, being about one individual km^{-2}. Skylark density in protected areas was up to 200 times that in the comparable adjacent non-protected areas where lands are used for camping, grazing and hunting. In the semi protected arable area, the Pivot farm, crested lark density was 80 individuals km^{-2}, which is 3 times their density in fully protected areas. Arable lands can form important alternative habitats for breeding larks, especially in more arid years. The results showed a remarkable impact of human activities on non-protected areas. A national action plan is highly recommended to preserve natural habitats and rehabilitate ecosystems by reviewing and controlling hunting, grazing, camping, and land use. Greater hoopoe larks and bar-tailed larks are becoming threatened species in Kuwait and the previous categorization as ‘low concern species’ according to IUCN is now not compatible with their current scarcity. The decline in lark numbers indicates the requirement for an action plan to safeguard and secure their natural habitats.

Keywords: lark species, distribution, habitats, abundance, density, protected area, non-protected area, arable area

3.1 Introduction

Kuwait is a harsh environment for birds since the climate is extreme and many areas are effectively desert. This presents considerable challenges to breeding birds. Furthermore, the country is relatively small, and the suitable land is heavily used for human activities. It is recognized that it is important to conserve natural habitats, but protected areas are limited to one large and four small reserves. It is important that we have a good understanding of the effectiveness of such protection, and of the best ways of protecting and monitoring change in the ecosystems represented. Indicator species are a useful tool in this context, and it is well proven that birds are good bio-indicators of the health of ecosystems (Martin & Possingham 2005).

Avifauna forms a major component of Kuwait wildlife; 365 avian species have been recorded in Kuwait State (Kuwait Environment Protection Society 2007) in spite of its small area and harsh climate. Furthermore, eight globally threatened bird species visit Kuwait: socotra cormorant *Phalacrocorax nigrogularis*, lesser kestrel *Falco naumanni*, saker falcon *Falco cherrug*, egyptian vulture *Neophron percnopterus*, greater spotted eagle *Aquila clanga*, eastern imperial eagle *Aquila heliaca*, houbara bustard *Chlamydotis undulata*, and Basra reed-warbler *Acrocephalus griseldis* (www.iucn.org). However, despite the large number of recorded bird species, only 24 of them are known to breed, of which 8 species breed regularly while others probably only breed occasionally when they mate in the country during winter visits (Evans 1994).

The yearly loss of resident breeding species in Kuwait may be more than can be compensated for by immigration of breeders from other areas, due to continuous land degradation and habitat destruction. On the other hand, it is impossible to declare all the important bird sites in the country as protected areas, so it is necessary to secure bird habitat by good planning and management. However, ecological habitats and their biota are exposed to degradation due to human population growth and urban expansion. In addition, uncontrolled degradation is accompanied with the difficulty of evaluating the real value of biodiversity and low public awareness.

Avian population dynamics are influenced by natural and anthropogenic factors. Due to climatic change, habitat quality can alter and reduced food abundance will constrain breeding. For example, in 1985, when there was little rain and many plants were damaged by severe cold in Kuwait, crested lark *Galerida cristata*, temminck's horned lark or horned lark *Eremophila bilopha*, black-crowned sparrow lark *Eremopterix nigriceps* and thick-billed lark *Rhamphocoris clotbey* did not breed. However, they did resume breeding when then weather conditions became suitable (Clayton & Wells 1987). Decline of avian populations induced by natural factors such as climatic changes, predation and diseases is still moderate in Kuwait and considered much less of a threat in comparison to non-natural factors (land use) which alters habitat and may lead to irreversible declines.

Larks *Aluadidae* form the bulk of the desert breeding species in Kuwait. Larks are usually shrub steppe species (Laiolo & Tella 2006 a) and only a few species can breed in the desert ecosystem. Larks possess a number of characteristics that enable them to be used as indicators of habitat integrity (Martin & Possingham 2005). They are relatively well studied and widespread, and can play an important role as natural indicators of habitat biodiversity, and maintaining their numbers is likely to require protection of important habitats (Evans 1994). Larks are passerines, and in Kuwait are widespread and found typically in sparse steppe vegetation lands. They are highly abundant in the Mediterranean and low latitude regions. Even though they are classified as low concern species (IUCN 2001), their populations have declined in recent decades and some species such as Dupont's lark *Chersophilus duponti* have been identified as nationally threatened in some European countries. Eleven out of 15 European lark species visit Kuwait during migration seasons (Table 1.1), but only four of them have been recorded as breeding: 1) greater hoopoe lark *Alaemon alaudipes*, 2) crested lark, 3) bar-tail lark *Ammomanes cinctura*, and 4) black-crowned sparrow lark or black-head finch lark (Gregory 2005). These larks are considered as resident, spending all year in the State of Kuwait, where they have adapted to the desert environment. Other larks (e.g. short toed larks *Calandrella brachydactyla*, lesser short toed lark *Calandrella rufescens*, desert lark *Ammomanes deserti*, dunes lark *Certhilauda erythrochlamys* and horned lark stay as visitors in fall and spring and breed occasionally when they find suitable circumstances (Gregory 2005). There are no breeding records for skylarks in Kuwait; they are only visitors (Al-Ghanem & Al-Shehabi 2006).

Such threats as are evident in Kuwait appear to be widespread and occur in other countries. The population density of skylarks *Alauda arvensis* has declined in Great Britain over the last four decades (Chamberlian *et al.* 1999). Crested Larks were known to be abundant in Central Europe in the middle ages (1200-1280). Their population in Switzerland declined dramatically after 1920 and the last breeding attempt occurred in 1991 (Hegelbach *et al.* 2003). In Kuwait, crested lark numbers have greatly reduced since 1979 prior to which it had been seen everywhere in huge assemblages;

for example, a thousand individuals were recorded in Ahmadi city in 1953 (Gregory 2005).

This study investigated the distribution of larks in relation to land use patterns in protected and non-protected areas of Kuwait. This was done to gauge the threats to biodiversity, and the efficacy of current conservation measures. I also investigated their adaptation to Kuwait's semi-arid climate.

3.2 Method

Study area and sites

The study area was located in open and protected areas north and west of Kuwait City and surveyed during winter and summer 2008-09. Selected areas were two protected areas: Sabah Al-Ahmed Natural Reserve (SAANR), 330km^2 in area; and Kabd Scientific Research Station (Kabd), 40km^2 in area; and two unprotected areas of similar landscape (behind Sabah Al-Ahmed Natural Reserve (B-SAANR), area 80km^2; and an area adjacent to Kabd Scientific Research Station (R-Kabd), 40km^2 in extent. The general landscape was characterized by short sparse bushy and grassy desert plants. Grazing, hunting and camping are forbidden in the protected areas whereas they are permitted in unprotected ones. I also sampled a semi-protected agricultural area, the Pivot farm (Pivot), 8km^2 in extent. The Pivot farmland contains 19 irrigated circular crops varying in radius from 0.5-0.9km, used mainly to grow seasonal leafy and cereal crops (foliage 80%, barley 10%, maize 10%). The pivot owner's camel and sheep herds graze continuously in the farmland.

I estimated bird species richness and abundance using distance sampling. Line transects were undertaken by driving slowly (<10km/h) along predetermined fixed routes and recording birds that were seen on either sides of that route. The transect length varied from 10-25km according to the relative site areas. Birds flying over the census area were included. To determine the exact perpendicular distance of recorded birds from the transect lines (in meters) I used a Bushnell Yardage Pro Sport 450 Laser Rangefinder (ranging accuracy ±0.9m). Each site was sampled in the morning (after sunrise and before midday) on between 4 and 6 visits. Fieldwork was conducted in winter from 20 December 2008 to 10 January 2009 to provide non-breeding season counts, and in spring from 1st March to 30th May 2009 to give breeding season counts, with 4 to 6 visits for each area in each season.

The data recorded were bird species, their group size and the distance of the individual or group from the transect. I also recorded vegetation cover, plant species and soil type along the transect to examine habitat preference (see Chapter 2).

Study species

I examined the total avifaunal species richness and abundance in the five study areas. But, particularly the focus is on resident breeding larks species; greater hoopoe lark *Alaemon alaudipes*, crested lark, bar-tailed lark *Ammomanes cinctura*, and black-crowned sparrow-lark *Eremopterix nigriceps* and visitor larks; short toed larks *Calandrella brachydactyla*, lesser short toed lark *Calandrella rufescens*, desert lark *Ammomanes deserti*, dunn's lark *Eremalauda dunni*, temminck's lark *Eremophila bilopha* and skylark

Alauda arvensis. In addition, species of dove and raptor were examined as two further groups.

Statistical analysis

Bird richness (number of species) and abundance (number of individuals within each species) were counted for the five sites. Population density of bird species were estimated using the Distance software (Distance 5.0) (Fuller *et al.* 2008 and Thomas *et al.* 2010) fitting different detection function models. Detection functions account for the fact that the probability of seeing birds will likely decline with their perpendicular distance from the transect, but the rate of decline may vary with the behaviour of the bird species, and the nature of the vegetation cover. To fit a detection function requires a certain minimum number of encounters, greater than 40 encounters is recommended (an encounter is defined as the single observation of an individual or group of individuals). Several detection models can be set up and run easily using different subsets of the data. The four detection models are: 1) uniform, 2) half-normal, 3) negative exponential and 4) hazard rate. Then, one of three adjustments: 1) Cosine, 2) Simple polynomial and 3) Hermite polynomial are chosen to generate the analysis of data in the Distance program. The combination of 4 detection models with 3 adjustments gives 12 possibilities of detection models that an observer can use. Furthermore, the observer can use a data filter option to analyse his/her data by truncating part of the data. Data Filters enable observers to try different truncation distances in order to examine the effects of exact data intervals and excluding some extended intervals. However, the truncate option must be used cautiously with a clear understanding of the data and possibilities of misleading outcomes (Buckland *et al.* 2001). The candidate models should also be selected upon specific criteria, such as goodness of fit (especially near zero distance).

Using this approach enabled me to take account of the fact that the probability of detecting birds might vary with species and habitat. The best detection model, g(y) is the one that has the lower Akaike's Information Criterion (AIC). I also calculated the mean group size of each species. Species with rare or few encounters could not be used to estimate density, but were used to determine avifauna richness in each area.

Density of greater hoopoe larks and bar-tailed larks were very low so in order to exceed the recommended minimum number of encounters required to conduct the Distance estimation, they have been merged with other species but analysed as stratified species. Stratified analysis helps to measure the density of every named species by using one detection function for all included species. Hence, it is important to choose species that have similar detection functions to generate the analysis. In my case, I used two groups; a passerine group and a non-passerine group for all species except for crested lark and skylark species whose encounter numbers alone exceeded 40.

3.3 Results

Detection functions

The best detection functions for specific species such as crested lark or skylark varied from one site to another according to the vegetation cover. Non-protected areas had higher detection probabilities than protected areas due to the reduced vegetation cover of the former (Figures 3.1 and 3.2). Probabilities of observing larks in protected areas declined rapidly with distance but stayed constant or decreased only slightly with distance in non-protected areas. Detection functions for observing crested larks approached zero after 30m in the Pivot due to dense vegetation cover, while declining to zero only beyond 50m and 60m in SAANR and Kabd respectively (Figure 3.1).

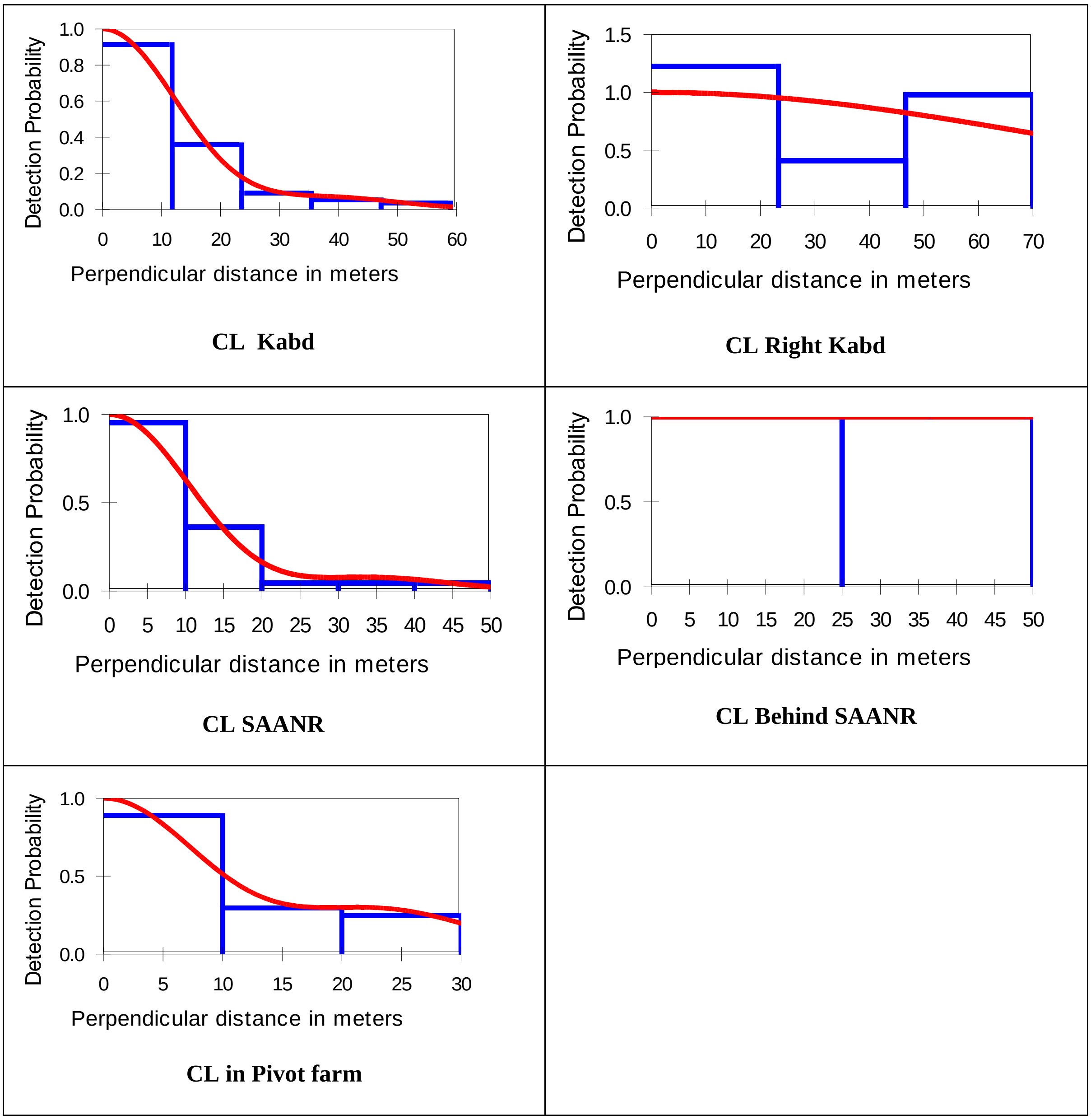


Figure 3.1 Detection functions of crested larks CL in the five studied areas. Probabilities of observing larks in protected areas (SAANR & Kabd) and farmland (Pivot) declined rapidly with distance but stayed constant or decreased only slightly with distance in non-protected areas (B-SAANR & R-Kabd). Non-protected areas had higher detection probabilities than protected areas due to the reduced vegetation cover of the former.

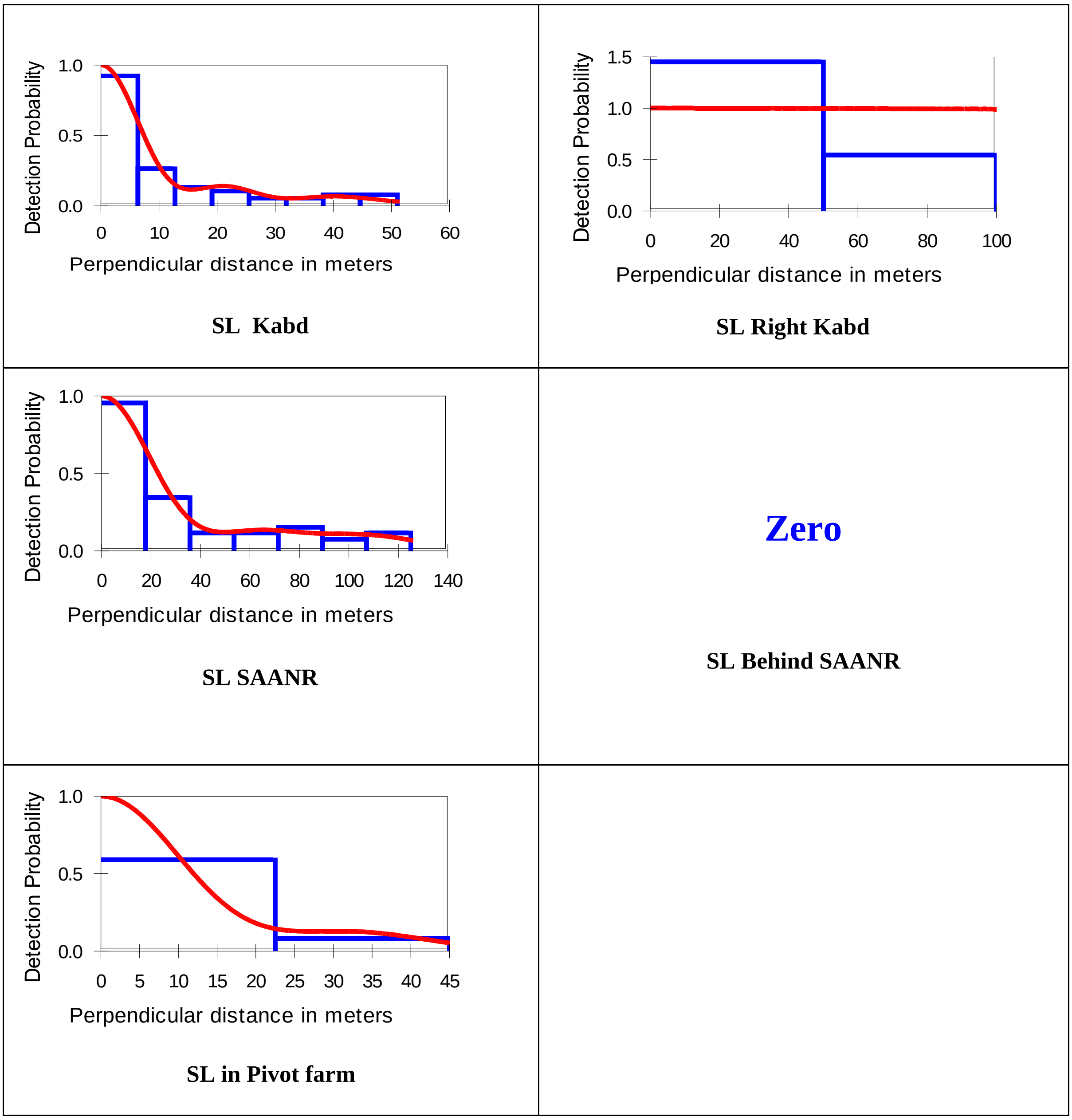


Figure 3.2 Detection functions of skylarks (SL) in the five studied areas. Probabilities of observing larks in protected areas (SAANR & Kabd) and farmland (Pivot) declined rapidly with distance but stayed constant or decreased only slightly with distance in non-protected areas (B-SAANR & R-Kabd). Non-protected areas had higher detection probabilities than protected areas due to the reduced vegetation cover of the former.

More birds were encountered in protected areas during the bird count survey. Protected areas have higher bird species encounters (per survey transect) than non-protected areas (Table 3.1 and 3.2). In the non breeding season, encounters of crested larks in Kabd was more than double in R-Kabd, whereas its encounter rate in SAANR was 8 times higher than B-SAANR. In the breeding season, encounter numbers of crested larks in Kabd was equal to R-Kabd while it increased dramatically in SAANR to 21 times higher than B-SAANR.

Table 3.1 Bird species encounters per survey during Dec-Jan 2008-09. Each survey comprised 4 traverses of the transect.

Pivot (10 km)	B-SAANR (25 km)	SAANR (25 km)	R-Kabd (20 km)	Kabd (20 km)	Area / Species / Length
29	4	32	32	81	crested lark
8	0	49	11	64	skylark
0	0	0	0	3	short-toed lark
0	0	0	0	41	black crown sparrow lark
0	0	19	0	10	bar-tail lark
0	0	6	0	0	greater hoopoe lark
201	0	1	0	96	doves
34	0	10	0	6	raptors

Table 3.2 Bird species encounters per survey during Mar-May 2009. Each survey comprised 4 traverses of the transect.

Pivot (10 km)	B-SAANR (25 km)	SAANR (25 km)	R-Kabd (20 km)	Kabd (20 km)	Area / Species / Length
240	4	87	32	30	crested lark
1	0	23	11	15	skylark
0	0	2	10	0	short-toed lark
0	0	0	6	9	black crown sparrow lark
0	0	5	0	2	bar-tail lark
0	0	5	0	0	greater hoopoe lark
91	2	19	0	89	doves
27	0	29	0	22	raptors

The lower AIC value for detection models g(y) for protected areas and some times for non-protected areas were Hazard rate models with cosine, simple polynomial or hermite polynomial adjustments. While AIC supported the choice of Hazard function, other measures of goodness of fit suggested this function led to over estimation of the density of some bird species. Empirical investigation of the density of territorial species such as crested larks and greater hoopoe larks were not compatible with the estimated density generated by the Hazard rate model regardless of the adopted adjustment model. The inadequacy of the Hazard rate models was also revealed by the huge confidence intervals generated in comparison to the half normal. Hence, I excluded Hazard rate models and chose the detection model listed in Tables 3.3, 3.4 and 3.5.

Table 3.3 Detection functions used in the studied areas

Species	Area	Type	Detection function
CL, Do sp	B-SAANR	simple polynomial	Uniform
CL, SL, ShtL, BtL, HL, Doves, Raptors	SAANR	cosine	Half normal
CL, SL, ShtL, BcSL, BtL, Doves, Raptors	Kabd	Cosine, hermite polynomial	
CL, SL, Doves, Raptors	Pivot	cosine	
CL, SL, ShtL, BcSL	R-Kabd	cosine	
	-	-	Negative exponential
	-	cosine	Hazard rate
	-	simple polynomial	
	-	hermite polynomial	

Table 3.4 Density of Passerine birds per square kilometer

Approval	Season	U 95%	L 95%	Density	AIC	Detection function/ adjustment	Area
Yes	Winter	39	18	26	1338.70	Half normal-cosine	SAANR
No	Winter	106	37	63	1315.79	Hazard rate- hermite polynomial	SAANR
Yes	Spring	86	35	55	2811.77	Half normal-cosine	SAANR
No	Spring	138	52	84	2791.93	Hazard rate- simple polynomial	SAANR
Yes	Winter	517	268	372	2319.35	Half normal-cosine	Kabd
Yes	Spring	171	80	117	2094.89	Half normal- hermite polynomial	Kabd
No	Spring	221	105	152	2049.08	Hazard rate- hermite polynomial	Kabd
Yes	Winter	495	179	298	987.57	Half normal-cosine	Pivot
No	Winter	4403	398	1324	920.85	Hazard rate- hermite polynomial	Pivot
Yes	Spring	388	171	258	3034.56	Half normal-cosine	Pivot
No	Spring	1404	649	955	2899.47	Hazard rate- hermite polynomial	Pivot
Yes	Winter	64	0.5	5.6	137.76	Uniform- simple polynomial	B-SAANR
No	Winter	399	5	45	130.64	Hazard rate- hermite polynomial	B-SAANR
Yes	Spring	2	0.5	1	110.46	Uniform- simple polynomial	B-SAANR
No	Spring	2	0.4	1	112.46	Half normal- cosine	B-SAANR
yes	Winter	38	14	23	904.48	Half normal-cosine	R-Kabd
No	Winter	44	15	26	902.25	Hazard rate- cosine	R-Kabd
Yes	Spring	2.6	0.3	1	86.95	Half normal-cosine	R-Kabd

Table 3.5 Density of Non-Passerine birds per square kilometer

Approval	Season	U 95%	L 95%	Density	AIC	Detection function/ adjustment	Area
No	Winter	6	0.2	1	91.49	Hazard rate- hermite polynomial	SAANR
Yes	Winter	1	0.2	0.5	93.54	Half normal-cosine	SAANR
No	Spring	12	5	8	668.91	Hazard rate- cosine/hermite polyn.	SAANR
Yes	Spring	9	4	6	679.99	Half normal-cosine	SAANR
No	Winter	85	34	54	766.07	Hazard rate- hermite polynomial	Kabd
Yes	Winter	16	9	12	890.69	Half normal- hermite polynomial	Kabd
No	Spring	188	66	112	741.55	Hazard rate- simple polynomial	Kabd
Yes	Spring	132	49	81	763.12	Half normal- cosine	Kabd
No	Winter	2860	972	1667	2614.93	Hazard rate- cosine	Pivot
Yes	Winter	416	166	263	2983.28	Half normal-cosine	Pivot
No	Spring	2436	527	1132	1101.55	Hazard rate- hermite polynomial	Pivot
Yes	Spring	405	63	159	1264.44	Half normal-cosine	Pivot

Breeding and non breeding seasons did not affect the detection model itself but suggested different adjustments. Half normal was the best candidate detection function for protected areas SAANR & Kabd and the arable land, the Pivot. Non-protected areas B-SAANR and R-Kabd have different detection functions. For both seasons, the best representative detection function for B-SAANR was the Uniform detection function with simple polynomial adjustment. Whereas half normal detection function was used for R-Kabd.

Richness and abundance of lark species were less than expected in most study areas. Only crested larks and black-head finch larks were present in abundance. Crested larks were restricted to SAANR and Pivot while black-crowned sparrow larks were abundant in Kabd.

In non-protected areas only crested larks were seen occasionally, but their densities were very low, only about two individuals in ten km^2 square kilometers. Lark density was very low in non-protected areas especially B-SAANR compared with the protected areas (Figure 3.3). B-SAANR was the poorest area where all larks were absent except very low numbers of crested larks. In winter, the highest lark density was in Kabd, being about 228 larks in a km^2. Density of skylarks had dropped dramatically seven times and thirty one times in Kabd and Pivot respectively by the summer season.

The arable area, Pivot Farm, had the highest density of crested larks in both winter and summer 68 and 118 individuals in km^2 respectively. Density of crested larks in Pivot during winter was twice what it was in Kabd and 14 times that in SAANR. Crested lark density increased in SAANR and Pivot but decreased in Kabd in summer.

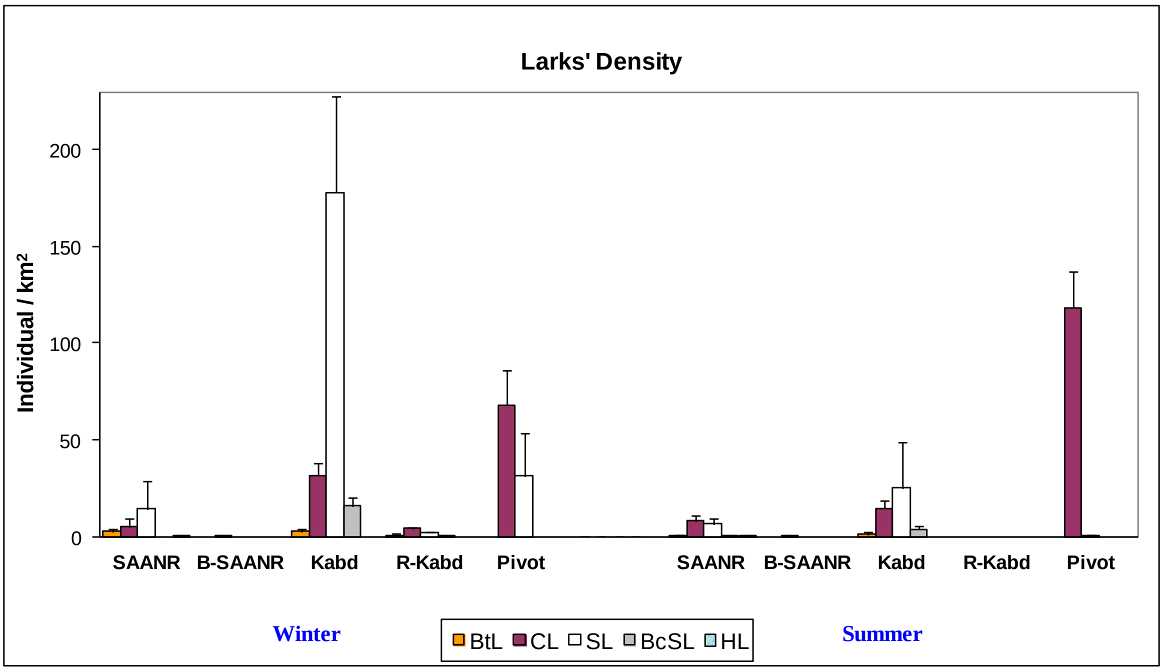


Figure 3.3 Density of different lark species in the five studied areas, BtL: bar-tail lark, CL: crested lark, SL: skylark, BcSL: black-crown sparrow lark, HL: greater hoopoe lark

Greater hoopoe larks were seen in SAANR only. Their density was very low in the winter and summer season. Black-crowned sparrow larks were observed in Kabd only with low density 4-16 individuals in square kilometers. Bar-tail larks occurred in SAANR and Kabd, but their densities reduced by 40-50% in summer.

Abundance of lark species differed among the studied areas. SAANR has four species of larks: bar-tail lark, crested lark, skylark and greater hoopoe lark. Kabd also had four species of larks similar to SAANR, but instead of greater hoopoe lark it was inhabited by black-crowned sparrow lark. The Pivot had only two species of larks (Figure 3.4).

Skylarks accounted for 64% of larks in SAANR during winter and 43% of larks in summer (Figure 3.4). In Kabd, skylarks formed the highest proportion of larks in both winter and summer seasons 78% and 56% respectively. In the Pivot, crested larks represented the majority of larks throughout the year. Crested lark density increased from 69% in winter to about 100% in summer.

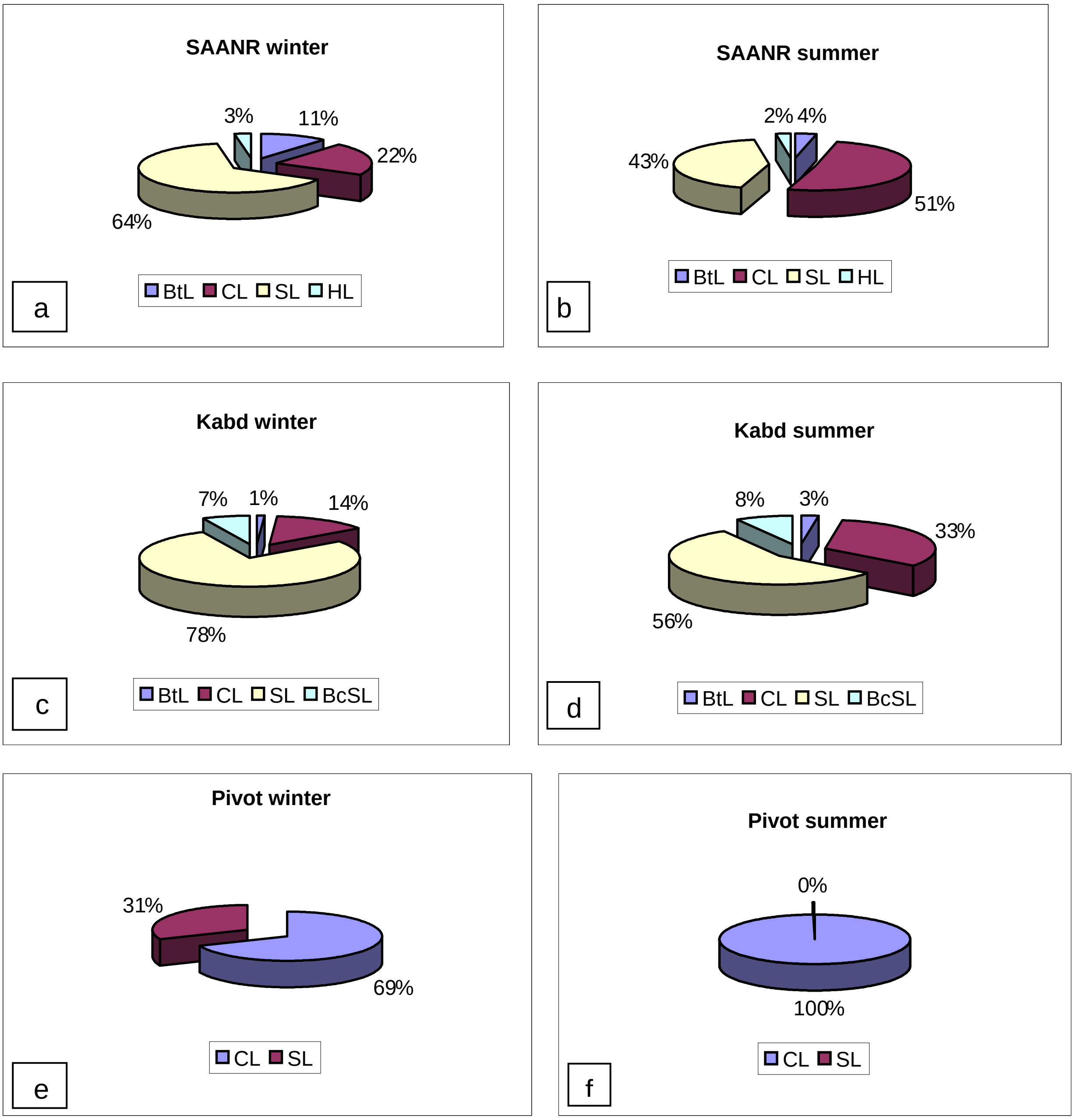


***Figure 3.4** Percentage of lark species in the protected areas and the Pivot; a. SAANR larks in winter, b. SAANR larks in summer, c. Kabd larks in winter, d. Kabd larks in summer, e. Pivot farm larks in winter, f. Pivot farm larks in summer. BtL: bar-tail lark, BcSL: black crown sparrow lark, CL: crested lark, HL: greater hoopoe lark, SL: skylark.*

Doves were absent in non protected areas (Figure 3.5) where there were no trees or tall shrubs at all (Chapter 2).

Both non protected areas B-SAANR and R-Kabd lacked doves in winter and summer seasons. Doves' density in SAANR was 5 individuals per 100 square kilometers in winter. In summer it increased to 1 individual per square kilometer. Kabd doves' density was about 21 and 55 times SAANR in winter and summer respectively. However, doves' densities were low in the protected areas SAANR and Kabd compared with the Pivot (Figure 3.5). Density of doves in the Pivot was about 8 and 1.5 times Kabd doves' density in winter and summer. By summer, doves' density in protected areas increased more than twice, while it declined to less than half in the Pivot.

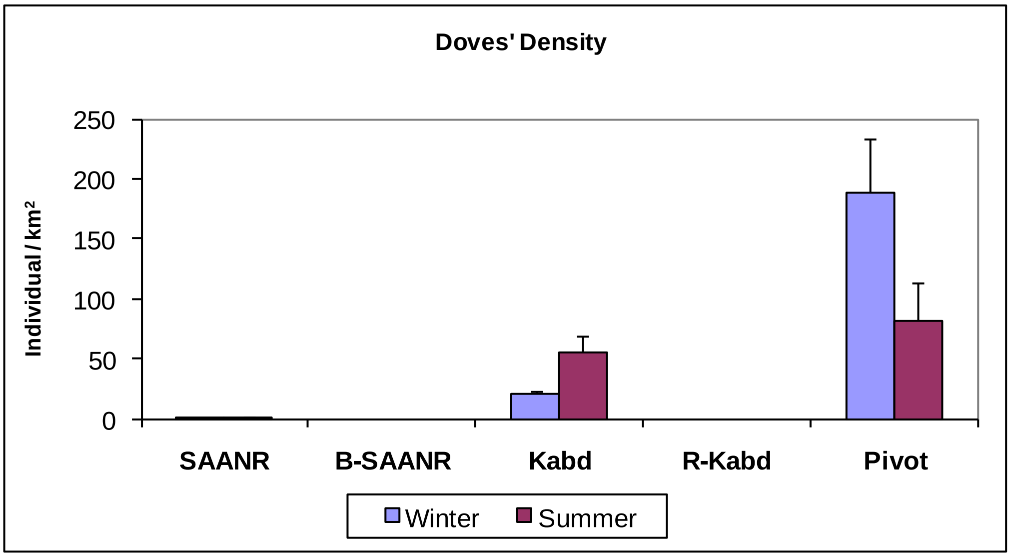


Figure 3.5 Density of doves in the five studied areas.

Raptors were absent in non-protected areas B-SAANR and R-Kabd during winter and summer seasons (Figure 3.6). In SAANR, raptor densities were 1 individual per 10 square kilometers in winter. By summer it increased 20 times. Density of Kabd raptors was 10 and 3.5 times higher than SAANR raptors in winter and summer respectively. The highest density of raptors was recorded in the Pivot. It was about ninety and nine times higher than SAANR and Kabd in winter respectively. In summer, density of raptors increased in the protected areas but stayed the same in the Pivot farm. Hence, raptors' density in the Pivot became 4.5 and 1.3 times SAANR and Kabd respectively.

Both non protected areas B-SAANR and R-Kabd lacked raptors in winter and summer seasons. Raptor densities were low in SAANR compared with Kabd and the Pivot (Figure 3.6).

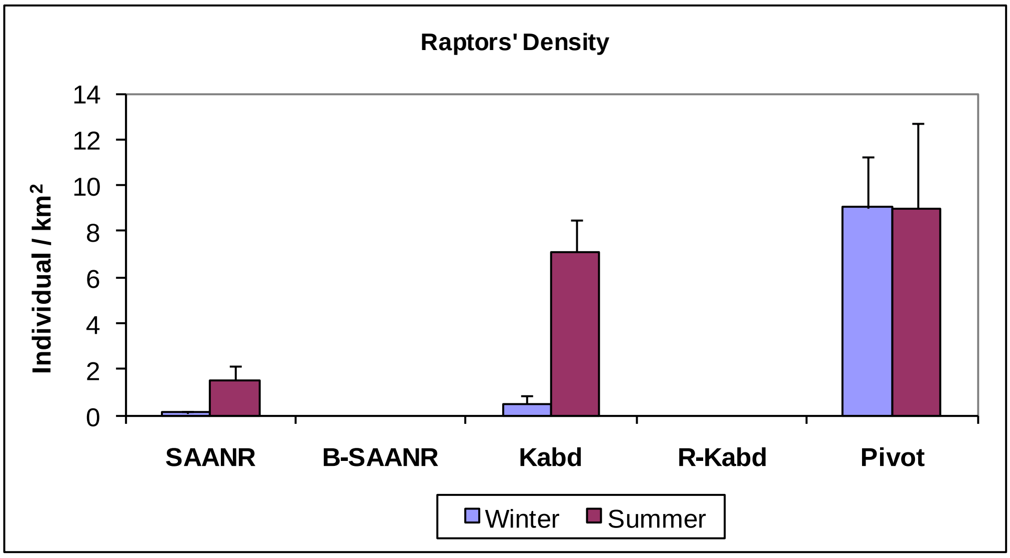


Figure 3.6 Density of raptors in the five studied areas.

Overall species richness and density

Avifaunal richness in protected areas was 1.7-4.3 times greater than non-protected areas in winter. In summer, richness of avifauna in protected areas reached 6-10 times higher than non protected areas (Figure 3.7). Thirty-nine bird species were observed in the protected area of SAANR compared with only four species in the adjacent unprotected area B-SAANR. In the protected Kabd, twenty-five bird species contrasted with just four in the comparable unprotected R-Kabd. The overall density of birds was much higher in protected areas than non-protected areas (Figure 3.8). Furthermore, summer showed more contrast between protected and unprotected areas than winter. Winter bird densities in protected areas (SAANR and Kabd) were 27 times and 15 times non-protected areas (Behind SAANR and Right Kabd) respectively. This ratio increased in summer to be 60 and 81 times to the advantage of protected areas. However, the arable land (Pivot farm) showed high bird species richness compared to both protected areas and non-protected areas in winter showing 1.5 and 1.4 times avifauna diversity of SAANR and Kabd respectively. But, in summer it showed about 1.4 times less than SAANR. Bird density was remarkably high in the Pivot, especially in summer when it was about 4 times higher than protected areas. SAANR had showed the highest avifauna diversity in summer. In addition, its bird species and density increased from winter to summer season by 3.8% and 59% respectively.

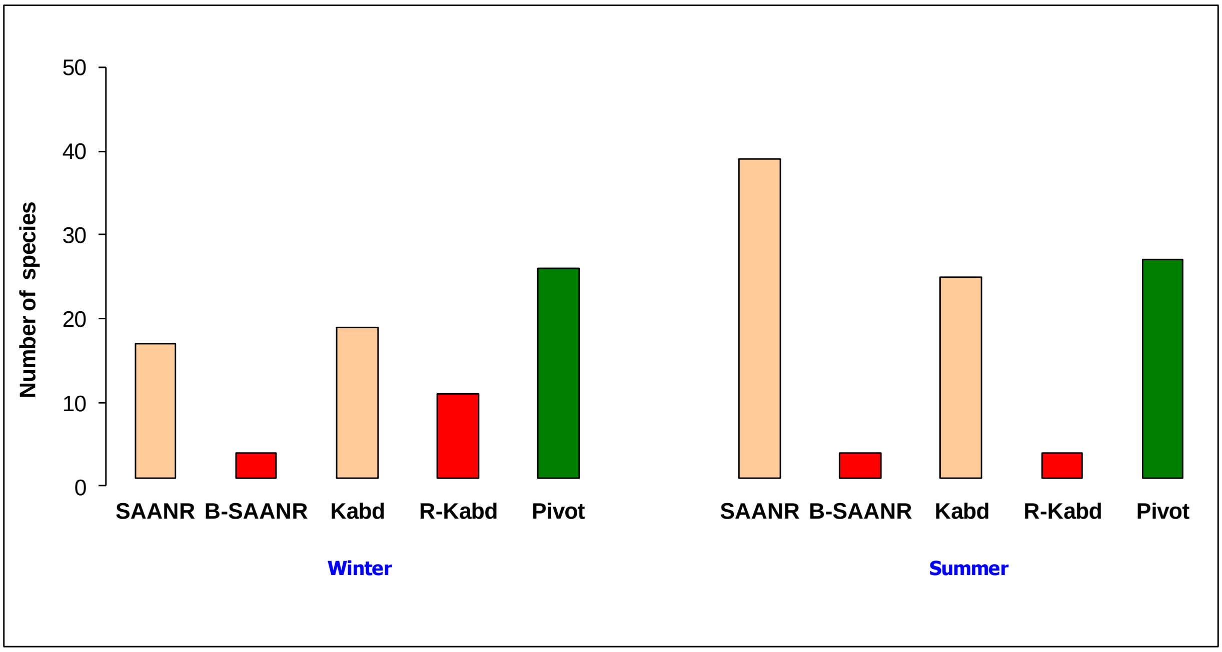


Figure 3.7 Avifaunal species richness in the five studied areas.

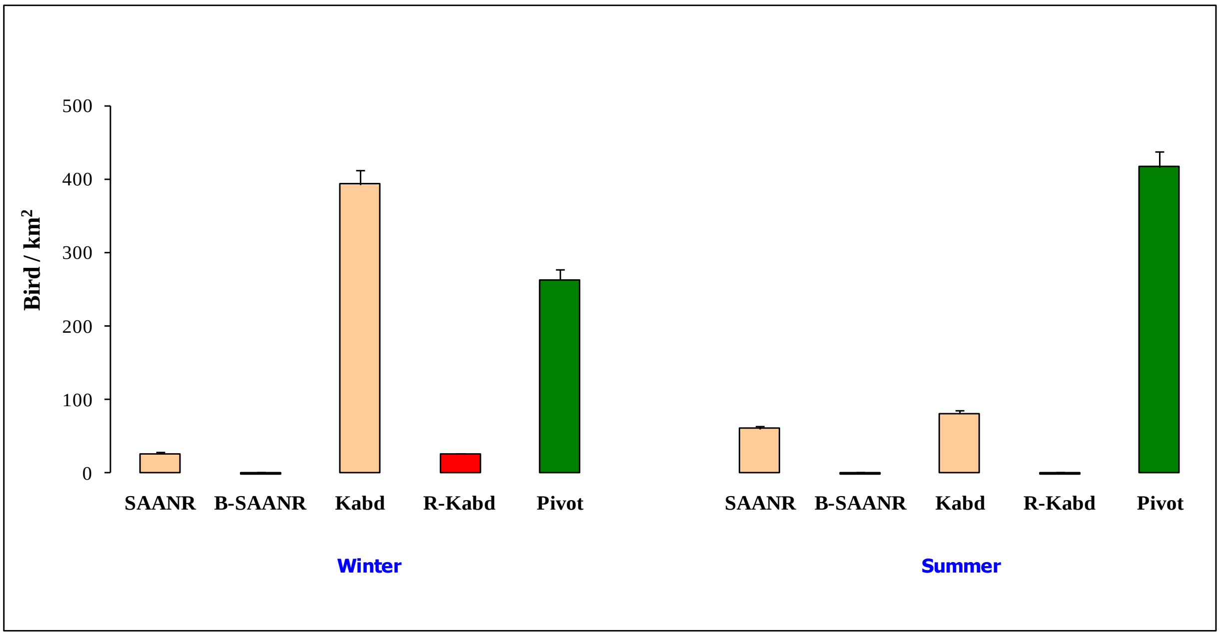


Figure 3.8 Mean bird densities with 95% confidence limit in the five studied areas.

In total 89 bird species belonging to 28 families were seen in the five studied areas during four seasons: winter, spring, summer and fall (Appendix 2). Avifauna richness was 74 and 44 in protected areas (SAANR and Kabd) compared to 5 and 11 in non-protected areas (B-SAANR and R-Kabd) respectively throughout the whole study period. 72 bird species were observed on Pivot farm, higher than Kabd but similar to SAANR. Birds from 23, 3, 15, 5 and 26 families were observed from SAANR, B-SAANR, Kabd, R-Kabd and Pivot respectively. Numbers of bird families in protected areas (SAANR and Kabd) were 7 and 3 times higher than non-protected areas (B-SAANR and R-Kabd).

3.4 Discussion

Habitats in Kuwait are heavily influenced by human activities. It is recognized that it is important to conserve natural habitats, but protected areas are limited to one large and four small reserves. It is important that we have a good understanding of the effectiveness of such protection, and of the best ways of protecting and monitoring change in the ecosystems represented. Indicator species are a useful tool in this context (Caro & O'Doherty 1999, Fleishman 2005), and it is well proven that birds are good bio-indicators of the health of habitat ecosystems (Haila 1985, Gregory *et al.* 2003, Gregory *et al.* 2005, Martin & Possingham 2005) and grassland integrity (Browder *et al.* 2002).

This study showed that there were significant differences between richness and density of larks in protected and non-protected areas and also between different protected areas.

An obvious conclusion from the results was the important role of protected areas in the conservation context. As an example, larks' species abundance and density in SAANR were remarkably higher than B-SAANR (Figure 3.9 and 3.10). Density of crested larks in SAANR was higher than B-SAANR 4 and 9 times during winter and summer respectively. Furthermore, all other larks' species were absent in B-SAANR area in both breeding and non-breeding seasons. Presence of crested larks in B-SAANR was temporary and might be affected by the proximity of niche areas of crested larks in SAANR protected area. However, the few encounters of crested larks in B-SAANR were correlated with accidental foraging in the border of SAANR protected area. The group size of most encounters of crested larks was one individual.

Absence of territories, mating signs and nests of crested larks in B-SAANR were a strong evidence of its lower habitat quality.

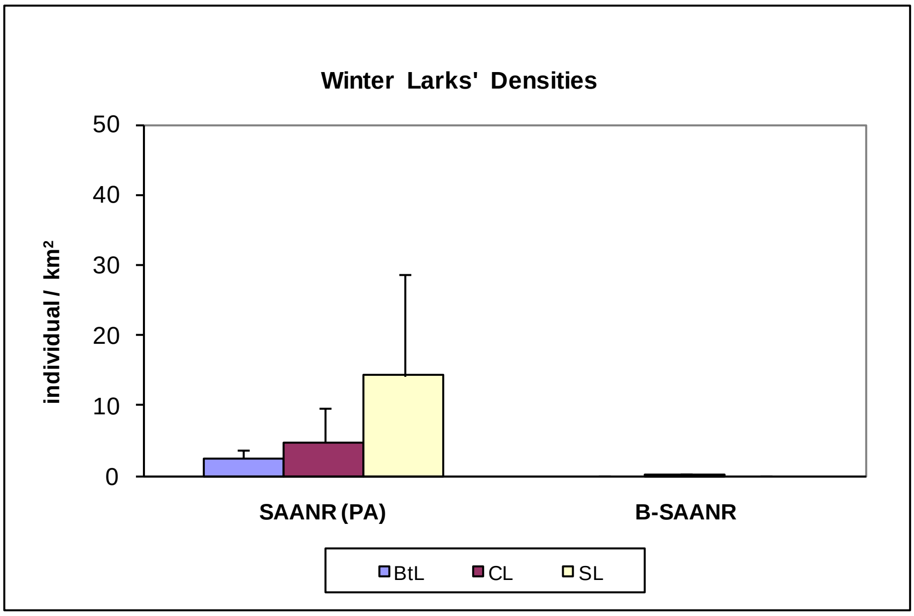


Figure 3.9 Density of larks' species in protected area SAANR and non-protected area B-SAANR during winter, non breeding season.

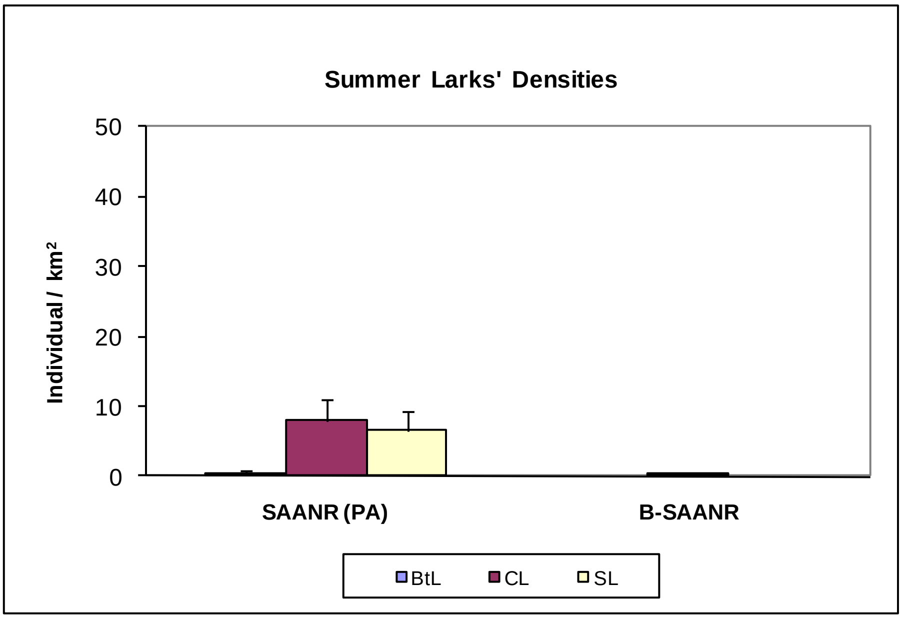


Figure 3.10 Density of larks' species in protected area SAANR and non-protected area B-SAANR during spring and early summer, breeding season.

A remarkable difference between larks' density in Kabd and R-Kabd during winter and summer (Figure 3.11 and 3.12) was evident. Density of skylarks in Kabd was higher than R-Kabd by 170 times during winter. Black-crown sparrow larks and bar-tail larks densities in Kabd were 40 and 20 times higher than R-Kabd during winter respectively. During summer, this difference declined especially for skylarks species which start migrating out of Kuwait after spring. However, density of larks in Kabd was also higher than R-Kabd in summer where skylarks and crested larks density were 30 and 20 times higher than R-Kabd respectively.

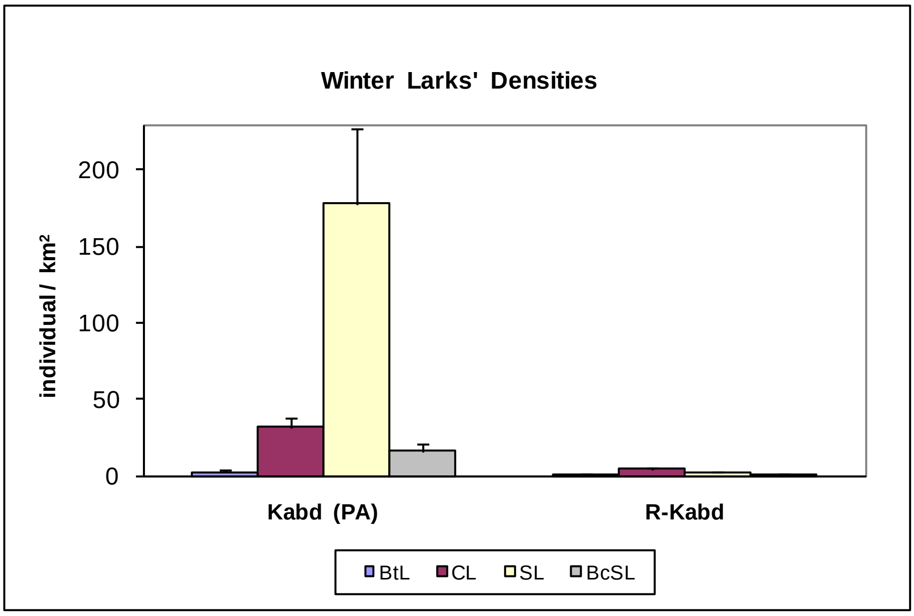


Figure 3.11 Density of larks' species in protected area Kabd and non-protected area R-Kabd during winter, non breeding season.

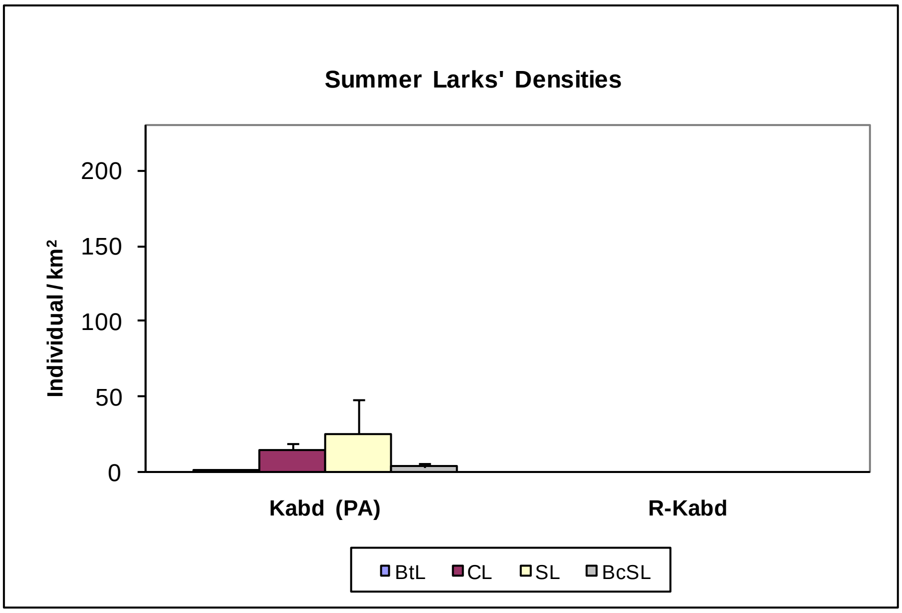


Figure 3.12 Density of larks' species in protected area Kabd and non-protected area R-Kabd during spring and early summer, breeding season.

Short-toed lark, lesser short-toed lark and skylark were winter visitors. Desert larks were rare in the study areas. Greater hoopoe lark, crested lark, bar-tail lark and black-head finch lark were resident species spending all the year in the country, where they are adapted to the desert environment. Greater hoopoe lark and bar-tail lark were solitary species foraging and seeking shade alone. Greater hoopoe larks were only found in SAANR, where habitat was open with sparse vegetation cover, notably sandy shrubby and grassy habitats. The vegetation cover is very dense (mostly alfalfa and barley crops) in the Pivot, in comparison to SAANR, and may not suit the greater hoopoe lark's demands. Greater hoopoe larks prefer sparse vegetation cover where they have better foraging access and ability to escape from predators. Some species of *Alaudidae* and ground foragers flee from predators instead of hiding (Wirsing *et al.* 2010). Accordingly, these species prefer stubble fields, short sparse vegetation cover, heath, moorlands, or till lands rather than dense vegetation cover or hedges (Eraud & Corda 2004, Gregory & Baillie 1998) because these all offer high visibility, which facilitates predator detection. Hence, the Pivot farm habitat is suitable for some larks but not for greater hoopoe larks.

Fruits of permanent native plants such as *Citrus citrollus*, which is similar to watermelons, supply greater hoopoe larks with water until mid summer reducing (but not eliminating) their need to approach water holes. Absence of greater hoopoe larks in Kabd and Pivot may be due to the absence of these plants from these habitats.

Bar-tailed larks occurred in SAANR and Kabd, inhabited ridges with steep slopes. All observations of bar-tailed and greater hoopoe larks comprised only one or two individual records. Bar-tailed larks were not observed around water holes throughout the year, even during summer. Hence, they may drink water from remote sites, or their water demand is low.

In Pivot, fresh vegetation cover (crops) and available water encouraged numerous crested larks to inhabit and breed in such habitats. Aridity of protected areas due to rainfall shortage during 2008-09 discouraged crested larks and other larks from inhabiting these areas during the breeding season.

Non protected areas were devoid of rare, vulnerable and near threatened bird species. Bird encounter rates in non-protected areas decreased with distance from protected areas. Thus, the few bird species that were recorded in non-protected areas were likely there due to the proximity to protected areas rather than to actual features of the unprotected habitats, which as discussed in the methods shared their broad physical features with protected areas.

Despite the small size of Pivot (8 km^2), it supported a richer avifauna than SAANR which is more than 40 times the area of Pivot indicating that arable lands can affect avifauna diversity positively. Accordingly, it is essential to co-operate with farm holders to integrate and improve biodiversity protection.

Density of skylarks had dropped dramatically (between seven and thirty fold in Kabd and Pivot respectively) by the summer season. This may be due to immigration, where they did not breed in Kuwait, remaining only as a migratory visitor species.

Both crested larks and black-crowned sparrow larks were water-dependent species, but black-crowned sparrow larks may be more so. Black-head finch larks perhaps preferred Kabd due to its site which is near to some farms rather than SAANR that is located in remote desert far from arable lands. The black-head finch lark is considered as a breeding species in Kuwait. But, there are no data available on their density in Kuwait. Available data are only associated with its presence or nest records in some farms or protected areas (Gregory 2005).

Greater hoopoe larks and bar-tailed larks were observed most often in open desert lands and absent in arable lands, whereas crested larks were abundant in both environments. Larks' encounter numbers were very low in non-protected areas. The study showed a remarkable difference between larks' density within protected and non-protected areas. Non-protected areas were vacant of most larks and other bird species due to habitat degradation (overgrazing and camping) and hunting. The scarcity of greater hoopoe larks and bar-tailed larks in Kuwait is not compatible with IUCN categorization as merely species of low concern. This study suggests greater hoopoe larks density is very low, being seen only in one protected area, SAANR. Abundance of crested larks was less than expected (IUCN 2008) and lower than recorded in the literature (Gregory 2005). The population of crested larks is expected to decline as a consequence of urban expansion, hunting and habitat degradation. This decline in larks' population density indicates the need for an action plan to secure natural habitats.

As doves are tree related species, their abundance was associated with the presence of trees. Presence of two long lanes of spaced tall trees >5m in Kabd coincided with sheep breeding which provide an indirect food supply, attracting doves and encouraging them to inhabit this area. SAANR has fewer tall trees than Kabd and a lower food supply for doves. Hence, dove density was considerably lower than Kabd. In the Pivot, the whole farm area is surrounded by a hedge of tall trees >8m, water and annual crops (e.g. maize, barley, alfalfa) were available periodically throughout the year. Hence, it is a suitable area for doves to inhabit year round.

In conclusion, conservation of natural habitats and biodiversity should be treated as a priority issue in Kuwait national strategy. Human activities should be controlled in order to save habitat lands. It is important to evaluate the effectiveness of protection, and monitoring change in the ecosystems represented. In this context, health of habitat ecosystems and grassland integrity can be measured by good bio-indicator species such as birds.

Chapter 4: Behaviour at Key Resources

Abstract

Water holes attract many avian species, particularly in semi-desert areas. I studied avifauna richness around a water hole in winter and summer. Desert resident species were not attracted to water holes in winter, when temperature is low. The water hole was almost found vacant in winter, even at midday. They spend most the day far away from water holes. As birds attracted to the water hole to drink and rest they may spend some times looking for food. During spring, I found herons chasing small passerines from tree to another to feed on them as a sign of food deficiency. Raptors (harriers, falcons, hawks, eagles) forage on prey in or around the water hole, such as small fishes, passerines, rodents or lizards. During summer, local birds such as crested larks were attracted to the water hole, especially at midday. Crested larks gathered in flocks of 5-65 individuals seeking shade under implanted tall trees during midday 1-30m away from the water hole. As the temperature rises the individual numbers increase around the water hole and their distance from the water body is reduced. In June-August, they usually start shading around the water hole at 8am and continue until 3pm.

Gregarious birds optimize vigilant attentiveness according to their group size. However, rate of vigilance varies. I studied the behavior of crested larks during winter and summer seasons in Kuwait. My hypothesis was that there are relationships between head up, crest up and closed eye verses group size as vigilance behaviours. I examined these relationships during foraging, shading and incubation. The study showed there are strong linkages between these signs and flock size. Forager individuals reduced their head up times as a benefit of group size enlargement. Ratio of crest down and closed eye individuals decreased with large flock size during shading. I found also a positive correlation between sitting individuals and crest up during shading. My hypothesis; lower crest or crest down means individual is being relaxed was consistent with my results. Shading or foraging in a large group is safer to reduce predator risks. A crested lark is a brave and cautious species at the same time. Its response relies on predator fitness and speed. A flock permits an adult *Varanus varanus* to approach to within one meter, while they fly away from hawks when there are several meters away.

Keywords: crested lark, winter, summer, farness, shade, vigilance, head up, crest up, closed eyes.

Section 1: 4.1 Water hole (Species compositon and abundance)

4.1.1 Introduction

Avifaunal richness and abundance depends on habitat quality and resource availability (Schneider & Griesser 2009). In semi-arid lands, water holes are a limiting factor for many bird species, particularly during late summer and autumn (Gubanich & Panik 1987). In dry environments, animals often orient their activities around water holes, and adequate access to water holes is an essential habitat requirement for many bird species (Freese 1978, Elder 1956). Schneider and Griesser showed that there is a negative relationship between avian species richness and distance from a water body (Schneider & Griesser 2009). Since the 1940s, construction of a water hole has been used as a wildlife-habitat improvement technique in desert environments (O'Brien *et al.* 2006). This management option could partially mitigate the negative effect of climatic changes on fauna and flora diversity (Schneider & Griesser 2009). There are a number of examples of the successful impact that increased water access can have. For example, an increase in open water increased the numbers and species of birds in prairie glacial marshes in Hancock County, Iowa, USA (Weller & Fredrickson 1973). In Zambia, the creation of artificial water supplies after annual rainfall shortage has been shown to be a very important habitat management tool for lovebirds *Agapornis nigrigenis* (Warburton & Perrin 2005). Hence, small artificial water bodies can be stepping-stones that help bridge the gap between natural wetlands and water bodies (Schneider & Griesser 2009).

Permanent and temporary water bodies, in addition to providing drinking water, also facilitate inter and intra-species interactions. However, while the surrounding vegetation cover can protect drinking animals, it may also provide hiding places for predators (Schnell & McDade 1992). Hence, game or prey species become a target for predators as they approach the water surface (Schnell & McDade 1992). Consequently, animals alter their behaviour to avoid this hazard (Cade 1965), for example becoming more vigilant to reduce their chance of being preyed on (Schnell & McDade 1992). Under predation pressure, gambel's quails are forced to alter their diurnal activity schedule in the summertime at Deep Canyon site to avoid the two most likely avian predators: cooper's hawk *Accipiter cooperii* and the prairie falcon *Falco mexicanus* (Goldstein 1984). In some cases, the presence of predators can deter animals from visiting the water body. For example, Beck *et al.* (1973) found gambel's quail *Lophortyx gambelii* did not visit water holes in the presence of raptors. Five species of columbiform were seen not drinking water directly as they arrive at a pool, waiting for a while in a relatively protected position as a precautionary response to falconiforms (Cade 1965). Drinking in groups can also provide protection due to increased vigilance. In doves for example, it has been shown that they drink in groups and their drinking bout length increases with group size, presumably as a consequence of the increased protection afforded by larger groups (Schnell & McDade 1992).

This part of my work in understanding the key habitat features affecting aviafaunal richness, I investigated inter and intraspecific interactions amongst birds at drinking areas in the very arid environment of Kuwait. I recorded changes in the species composition and abundance of birds present throughout the day at a water hole in a protected area (Section 1). I also investigated the relationships between group size and vigilance behavior in the vicinity of the water holes (Section 2).

4.1.2 Methods

Study areas and species

This study was carried out in Sabah Al-Ahmed Natural Reserve (SAANR), 60km away from Kuwait city in 2008-9. SAANR is a semi-arid protected area ($330km^2$) located north Kuwait Bay. Talha water hole, 30m in diameter and 50cm depth, is the only permanent artificial water hole in SAANR. The water source is an underground, brackish well. Some local sea fishes have been brought to the Talha pool by the reserve management. The other two water sources in the area are very limited: a) a small concrete basin water hole, 1m radius and 20 cm depth, b) an irrigation pipeline from which water drips. Talha water hole is surrounded by dozens of planted trees *Aciacia sp*. and some *Ziziphus spp.* The tall and large trees provide extensive shade during the middle of the day, where birds can shade and rest near the water hole. Crested larks *Galerida cristata* and collared doves *Streptopelia decaocto* are the most common sedentary species visiting the water hole. In Section 1, I examine the species richness, and intra and interspecies interactions. I also recorded the response of crested larks to other animal species approaching the water hole. In Section 2, I examine aspects of the vigilance behaviour of flocks in the area of the Talha water hole.

The water level of Talha water hole changed in 2009 after its deepening and the building of a sand bank barrier (about 80cm) around the water hole. This sand bank permitted an increase in the amount of water "overflowing" which provide the main area of salinity water.

Data collected and analysis

I chose seven spaced trees surrounding Talha water hole for this study (Figure 4.1 and 4.2). Distance from each tree to the water hole was measured. Ten visits in both winter (1st to 10th January 2009) and summer (21st to 30th June 2009) from 8am-4pm were carried out to identify bird species and their individual numbers resting under these trees. In 2008, most birds gathered on the islands in Talha water hole. But in 2009, the change of the water level in Talha water hole contributed to reducing the number of birds within those islands and dispersed birds somewhere around the water hole.

Figure 4.1 An aerial image of Talha water hole, Google Earth 2008. The water hole itself is indicated by the red circle; the trees used for this study are indicated by arrows.

Figure 4.2 A landscape view of Talha water hole, filled by brackish water as seen from the sub-little area surrounded by blocks (Gregory 2008)

This study aims to test the value a water hole can play in a desert environment by recoding: 1) the richness of biodiversity around Talha water hole, 2) the effect of temperature on the distribution of birds around the water body and their distance from the water body seasonally and diurnally, and 3) the influence of the water hole on bird behaviour such as shading, drinking, roosting, foraging and predation.

Monitoring was done from a vehicle as hide, parked near the edge of the water body (Figure 4.3). Counts were made at hourly intervals of the number of birds of different species present. In total, I observed the birds for 160hr (20 days; 1-10 January and 1-10 June 2009). Lizards and mammals were also recorded. The use of the water hole was recorded in winter 5-10˚C and summer 40-75˚C (see also Chapter 5 Thermal Challenge). In addition to counts, I recorded the proportion of birds drinking and in the shade and incidences of predation or kleptoparasitism. More detailed studies on vigilance behaviour were also under taken – see Section 2 of this chapter.

***Figure 4.3** Talha water hole. 1) A favorable roosting area inside Talha water hole where some birds, especially crested larks gather in midday summer.*

In addition, animal species that were encountered during other seasons (spring and fall) were also recorded in order to count the extent influence of water hole on attracting biodiversity.

4.1.3 Results

The study shows that 96 animal species used the water hole; 91 bird species, 3 mammals and 2 lizards throughout 2009 (Appendix 4). Six of the bird species are resident (sedentary) species and 85 are migratory species. Many avian species were attracted to the Talha water hole in spring and fall, but very few in winter and summer (Figure 4.4). In summer, species diversity is low in comparison to other seasons, but the actual number of individual birds attracted to Talha hole is much larger than in other seasons (160 crested larks in summer compared with 6 crested larks in winter during midday time). The predominant bird species in summer were: crested larks 89.9%, laughing and collared doves 3.9%, house sparrows 4.2% and other species 2%. Desert resident species were not present at the water hole in winter when temperature is low. During winter, the resident species spend most the day far away from water holes. The peak number of avian species was in spring and fall, when birds visited Kuwait throughout their migration path.

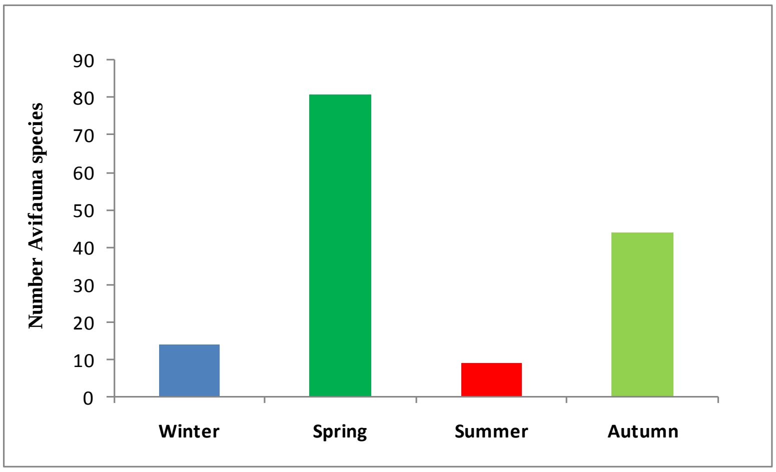


Figure 4.4 Seasonal Bird species richness around Talha water hole during 2009.

During midday summer, many birds roosted in the shade under trees located within the Talha water hole itself (Figure 4.5).

***Figure 4.5** A shaded area inside Talha water hole. This appeared to be the best roosting area for many bird species as well as crested larks.*

This roosting area, which is surrounded by water, was clearly very attractive to most avifauna species, especially when ambient temperature rose. The beneficial value of this shaded area involves three factors: 1) wet substrate ground with a lower temperature than other dry shaded grounds where birds can sit to cool their bodies.; and 2) access to water to drink frequently as needed with minimum effort while they are shading from the sun (Figure 4.6) in comparison to other birds who fly to the water hole 3) some protection from predators.

***Figure 4.6** A wet shaded area inside Talha water hole. Its wet substrate ground has a lower temperature than dry shaded grounds around Talha water hole. Substrate-wetness leads to evaporation and evaporation causes a substrate to cool down (as for human skin with sweat). The birds apparently take advantage of this.*

The crested lark is the most abundant species all the year. Crested larks gathered in flock sizes of 5-65, shading under tall trees during midday 1-60m away from the water hole (Figure 4.7), and also within the water hole (Figure 4.8). Crested lark numbers in shade around the water hole varied between 80-170 and 3-20 individuals in summer and winter, respectively.

Figure 7 shows the changes in the numbers of crested larks present at different times of day in summer and winter. As temperature rises, numbers increase around the water hole and their distance from the water reduces (Figure 4.8). In June-August, they usually move to shaded areas around the water hole at 8am. During midday in summer, ambient temperature is about 70°C and 50°C in sun and shade respectively. According to my observations on nest temperatures in Chapter 5, the difference between temperatures in shade and sun positions exceeded 20°C at midday in the summer season. Temperature in full sun sometimes rises up to 76°C (see Chapter 5). My results showed that crested lark group size was negatively correlated with distance from the water hole.

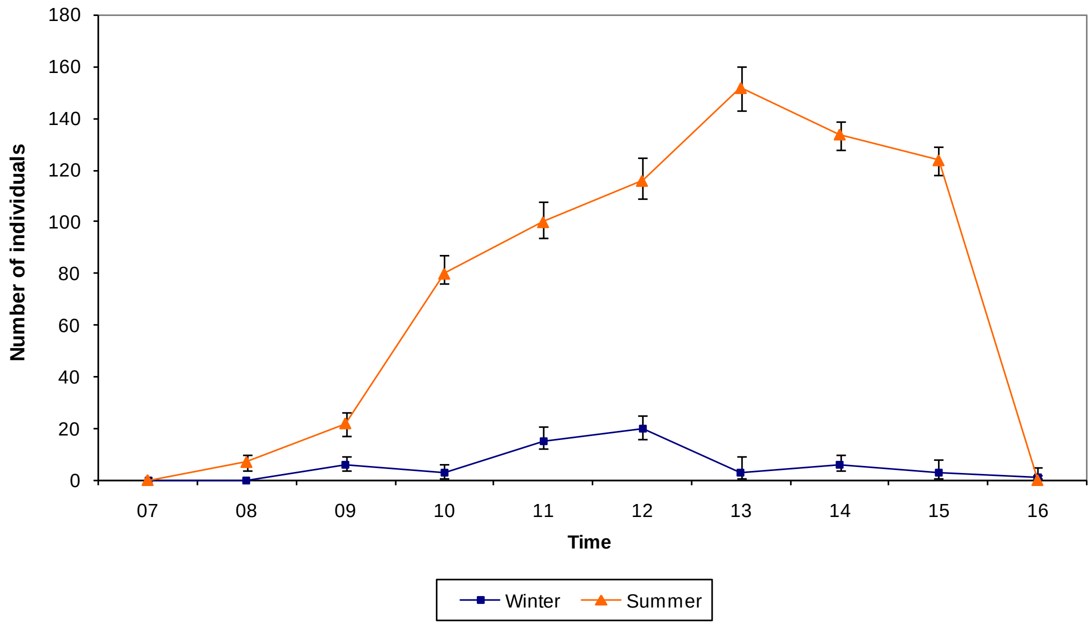


***Figure 4.7** Talha water hole diurnal use by crested larks during Jan (blue line) and June 2009 (red line). Standard error bars represent the maximum and minimum bird recorded during ten days. Number of crested lark increased with time and reach its maxima at after midday from 13-15 in the summer season and around 11-12 in winter.*

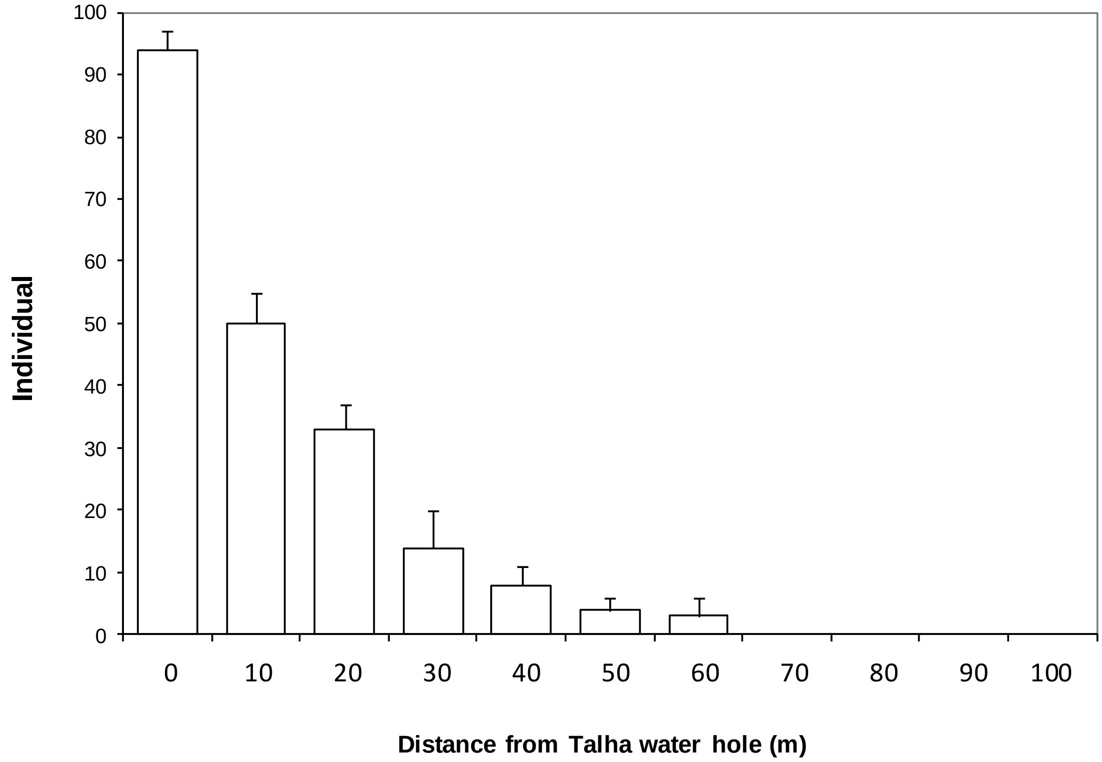


***Figure 4.8** Distribution of crested larks around Talha water hole at midday summer during 21st to 30th June 2009. Standard error bars represent the maximum and minimum bird recorded during ten days. Crested larks tend to be close to the water hole in midday in summer where their group size decline as distance from the water hole increased.*

Water with plant cover is limited inside Talha water hole, only two places being shaded by *Acacia sp* trees (Figure 4.9). In the normal phase, a suitable amount of water is available which did not cover small islands within the waterhole, whereas in the overflow phase water covers most of these small islands. The deepening of Talha water hole decreased the available space area of these islands where crested larks roost mainly in midday of summer season. Shallow hole with normal fill is more preferable for crested larks by which they have shaded areas inside the water hole (small islands) to roost and easily get access to water.

Figure 4.9 Talha water hole after deepening its basin during 2009. Red circles are the roosting areas used by crested larks in midday summer are now under water

Deepening the water basin several times during 2009 altered the form of the water body. One patch was covered by grass and the other patch was flooded 2/3 by water. Hence, many bird species were deprived of access to the water banks. Crested larks avoided one of these shaded areas within the water hole when dense grasses grew up, presumably to avoid possible hidden predators. Consequently, total number of crested lark flocks which was shading inside the water hole on the small islands during 2008 declined in 2009 (Figure 4.10).

On the other hand, annual plant species increased and formed 3 small patches around the water hole after the flooding of the water basin. Thus, birds' drinking and shading places were shifted some distance.

These changes in the structure of the water hole had an effect on the animals using it.

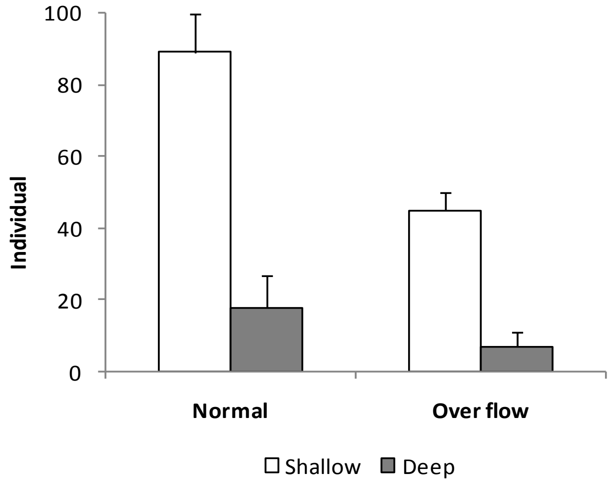


Figure 4.10 Comparison of mean abundance and standard error of crested larks within Talha water hole during summer. Normal phase with suitable amount of water which did not cover small islands within the waterhole (n=10) while over flow phase when water covers mostly these small islands (n=10).

A small number of greater hoopoe larks, a solitary species, were also recorded around the water hole. Most observations of greater hoopoe larks were of one individual drinking water or shading alone or with two or three crested larks.

Collared and laughing doves are sedentary species breeding in *Aciacia sp*. and *Ziziphus spp* trees surrounding Talha water hole. They were wary in approaching the water hole, drinking water for only a short time.

The water hole attracted a number of predatory species. Terrestrial predatory birds such as raptors appeared to stay at the water hole for only a short time to hunt. Aquatic predatory birds, on the other hand, appeared to stay for a long time, up to several hours, to feed on fish. However, since individual birds were not marked it was not possible to quantify this. During spring, I found cattle egrets *Bubulcus ibis* chasing small passerines from one tree to another to feed on them, presumably reflecting a shortage of fish prey. They were observed to swallow several barn swallows *Hirundo rustica* (Figure 4.11). A barn swallow was the most common prey item taken by predatory birds at the water hole. It was also seen being taken by squacco heron *Ardeola ralloides* and red-backed shrike *Lanius collurio.* Ortolan bunting *Emberiza hortulana* was also seen being eaten by cattle egrets and squacco herons. An immature crested lark was seen being eaten by a steppe buzzard *Buteo buteo vulpinus*. Sparrow hawks were observed predating hoopoe *Upupa epops*, yellow wag-tailed *Motacilla flava*, house sparrow *Passer domesticus* and chasing crested larks. Other preys taken were wagtails, warblers and pipits (Appendix 4.2). Thus quite a large number of predatory species are present at the water hole, and vigilance behaviour is very important.

Figure 4.11 Cattle egrets Bubulcus ibis catching barn swallow Hirundo rustica while the later feed on insects flying over Talha water hole.

The desert monitor *Varanus griseus* was the predator most frequently recorded. It presented a frequent predation risk to birds in the water hole area. It was very active at midday (particularly in summer), using shaded areas under vegetation cover to look for prey. The desert monitor swims in the water body to catch birds while they are drinking, or catches them when they are shading or even perching on low droopy tree stems. (It was also seen attacking the short-toed eagle, and by several bite attempts tore the latter’s tail).

Mammal numbers were relatively low. A red fox *Vulpes vulpes* was seen drinking water at midday in summer. One dead red fox was also found near the water hole. Its scratched and bloody face implied an attack, probably by stray dogs.

Small mammals recorded were long-eared hedgehogs *Hemiechinus auritus* and the Libyan jird *Meriones libycus*. The former was seen frequently and dead bodies were found in different places away from the water hole. The later was seen predated by booted eagle *Hieraaetus pennatus.*

Neither black-crown sparrow lark nor bar-tail lark, which were seen in SAANR area, were seen at Talha water hole. Black-crown sparrow larks were seen near the coastal area of SAANR in winter and spring. Absence of the black-crown sparrow lark at the Talha water hole may be due to its low density in SAANR. However, black-crown sparrow larks were seen gathering around a small water hole in Kabd in summer to drink water (Chapter 3). On the other hand, bar-tailed lark were not seen around Talha water hole and not seen drinking water any where. Bar-tailed larks which inhabit ridges and remote habitats may drink from other water sources such as droplets from irrigation pipes.

Section 2: 4.2 Vigilance behaviour in crested larks (winter & summer)

4.2.1 Introduction

The ability of bird flocks to detect a predator is generally higher than that of a single individual because of the 'many eyes effects' (Powell 1974). Scanning the environment for approaching predators is generally known as vigilance behaviour. Many studies have been done on vigilance behaviour in birds using various species (e.g. Metcalfe 1984a, Metcalfe 1984b, Lima 1994, Cresswell 1994 a, Alves & Cavalcanti 1996, Verdolin 2006). These studies usually involve measuring scanning behaviours such as the number of times individuals raise their head and scan the environment, usually during foraging periods but sometimes also in other contexts such as in sentinel behaviour.

Anti-predator strategies can differ among species for many reasons, linked to the adaptive value of differing anti-predator behaviours. *Alaudidae* and some other ground foragers flee from predators instead of hiding (Wirsing *et al.* 2010). Hence, these species prefer stubble fields, short sparse vegetation cover, heath, moorlands, or cultivated land rather than dense vegetation cover or hedges (Eraud & Corda 2004, Gregory & Baillie 1998) offering high visibility which facilitates predator detection. High vegetation cover can reduce visual predator detection and increases potential predation risk. On the other hand, for some species, vegetation aids concealment. Consequently, depending on the species, habitat structure (vegetation form and height) can alter predation risk positively or negatively (Whittingham & Evans 2004, Whittingham *et al.* 2004).

Skylarks avoid high vegetation cover as well as hedges around their nests to increase visibility, and aid detection of predators such as hen harriers *Circus cyaneus* in Norfolk, Cambridgeshire and Hampshire that are attracted to skylark foraging areas (Clark *et al.* 2003). Predation risk can be very high. Probability of predation on breeding crested larks *Galerida cristata* and desert larks *Ammomanes deserti* in Negev desert of Israel was 76% and 85% respectively (Shkedy & Safriel 1992 a). Crested larks are more vigilant than desert larks and use more concealed nest sites as an adaptation to high predation risk (Shkedy & Safriel 1992 a).

An experimental aviary study on 12 Barbary doves *Streptopelia risoria* between 10:00 and 12:00 day hours showed that birds in high-risk flocks reduced the time spent with their eyes closed after a tame ferret *Mustela furo* was allowed to patrol (on a leash) the aviary perimeter in comparison with lower-risk flocks that were not exposed to a predator (Lendrem 1984). Individual vigilance of both high-risk and low-risk birds has generally been found to decrease as flock size increases due to cooperative vigilance (Lendrem 1984). But, vigilance of individuals and flocks of high-risk birds are higher than those of lower-risk (Lendrem 1984). Furthermore, frequency of ‘peeks’, that is opening the eyes to look for predators, and duration time of peeks, declined as flock size increased (Lendrem 1984).

As is clear from Section 1, predation risk in the area of the Talha water hole seems to be high. I therefore examined the vigilance behaviour of the most common lark species that I encountered the crested lark. In the middle of the day in summer, crested larks tend to roost in shady areas and flock size is variable. They are potentially very vulnerable to predators during this time. I expected that crested larks might show signs of being less alert as indicated by lowering the crest when they are in a large group compared with being in a small group or alone. I examined the relationship between group size and the number of birds with the crest raised. I also monitored whether or not roosting individuals had their eyes closed using scan samples and examined the relationship between group size on the amount of time individuals had their eyes closed and how this varied with whether the bird as sitting or standing. Typically crested larks are found in steppe, semi-desert and desert zones, especially low land plains and levels (Cramp 1988). Individual distribution pattern is a consequence of behavioral decisions. Many factors such as predator avoidance, shelter from weather and food quantity play a role in determining habitat preferences (Robinson & Sutherland 1999). The crested lark is not a markedly gregarious species and generally appears singly, in pairs or in small parties. However, large numbers may be attracted to favorable food or water supplies (Cramp 1988). Therefore, it is possible that the birds are not well adapted to being in groups and they may not incur the benefits, which could potentially make them more vulnerable to predators when they collect together in groups around environmental resources such as food, shade or water.

4.2.2 Methods

Data Collection

I collected data on the behaviour of crested larks in different group sizes both at the Talha water hole and in foraging areas. In the winter (December - January) of 2009, the behavior of crested larks foraging in different group sizes was observed in two areas: Sabah Al-Ahmed Natural Reserve (SAANR) and an area of arable land named locally as Pivot farm. SAANR is 330 km^2 whereas the Pivot farm is 8km^2. The former represents natural sparse vegetation and an open landscape and the later represents agricultural land. Crested larks are ground foragers. I examined the effect of group size on the rate at which individuals scan the environment. Scanning was easily recognized by the adoption of the ‘head-up’ position. Data collection was delayed 20 minutes after approaching a group of crested larks to eliminate the effect of disturbance. A monitored individual was selected randomly and observed for 1 minute. The number of scans per minute was recorded. Also, group size and density of crested larks were recorded. Individuals that foraged within 4 meters of each other were treated as one group, where beyond this distance individuals seem to be unrelated. Density of a group was defined according to three categories of inter-individual distances: sparse (≥1m apart), moderate (0.5-1m apart) and dense (≤0.5m apart). Group size was also recorded. For this part of the analyses, group sizes of one were excluded.

In summer (April-June), crested larks tend to spend most midday hours in shaded areas near the Talha water hole. The number of individuals with the crest-up and crest-down in a group was recorded among the shading groups. Posture of individuals was recorded as ‘stand-up’ or ‘sit-down’ in order to see how the position of the crest was linked to alertness.

Length of time with closed eyes was counted in 60sec periods. Each individual within a group was sampled only once. Birds were again categorized as to whether they were standing or sitting. Data were not collected during periods of high disturbance.

All observations were done from a vehicle which served as hide. Binoculars, a countdown timer and manual counter were used to collect the data. Head-up observations were done in the morning when crested larks were actively foraging. The data on crest position and eye closure were collected around midday during the time birds were shading from the sun. SPSS version 15 was used to analyze the data.

4.2.3 Results

Overall, Flock size was significantly higher in the summer study period (Figure 4.12).

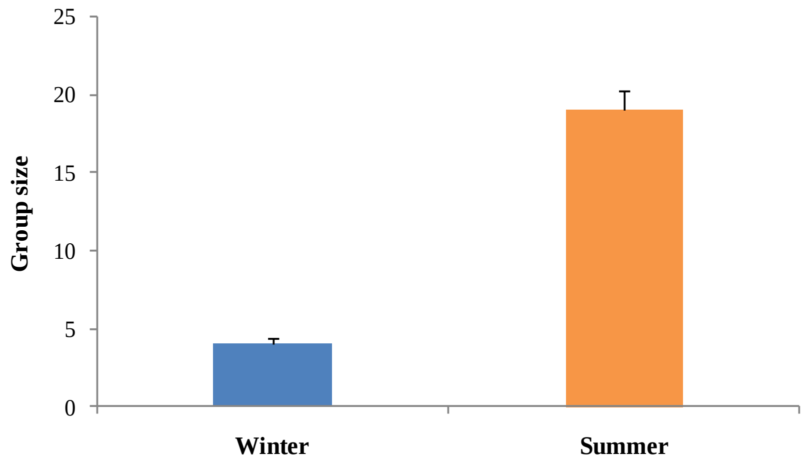


Figure 4.12 The mean flock size of crested larks and 95% confidence interval in winter and summer. t-value= 12.902, df = 109, P value < 0.001.

Crested larks did not drink water simultaneously; some individuals drank while others were vigilant.

I. Winter foraging flocks

In winter crested larks were seen foraging solitarily, or in small parties; 81.3% of 114 observations were flocks of up to 5 individuals and the rest was 7-13 individuals.

4.2.4.1 Vigilance during foraging

There was a strong negative relationship between group size and scanning rate (Figure 4.13).

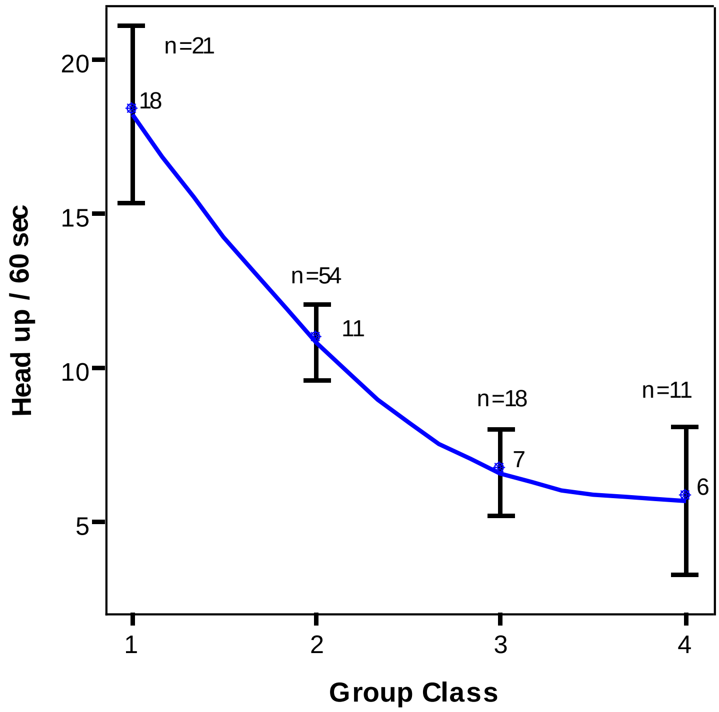


Figure 4.13 The mean number, and 95% confidence intervals, of scans per minute made by crested larks foraging during winter December-January in relation to group size. Group sizes have been lumped into four classes only for the purposes of the figure. Class 1: one individual, class2: 2-4, class3: 5-8, class4: 9-13 individuals. Correlation coefficient of group size and number of scans/minute - 0.537 (n=104), degrees of freedom = 103, F= 26.975, P value < 0.001.

Also, scanning behaviour was influenced by group density, with less scanning being done in denser groups than in sparse groups (Figure 4.14).

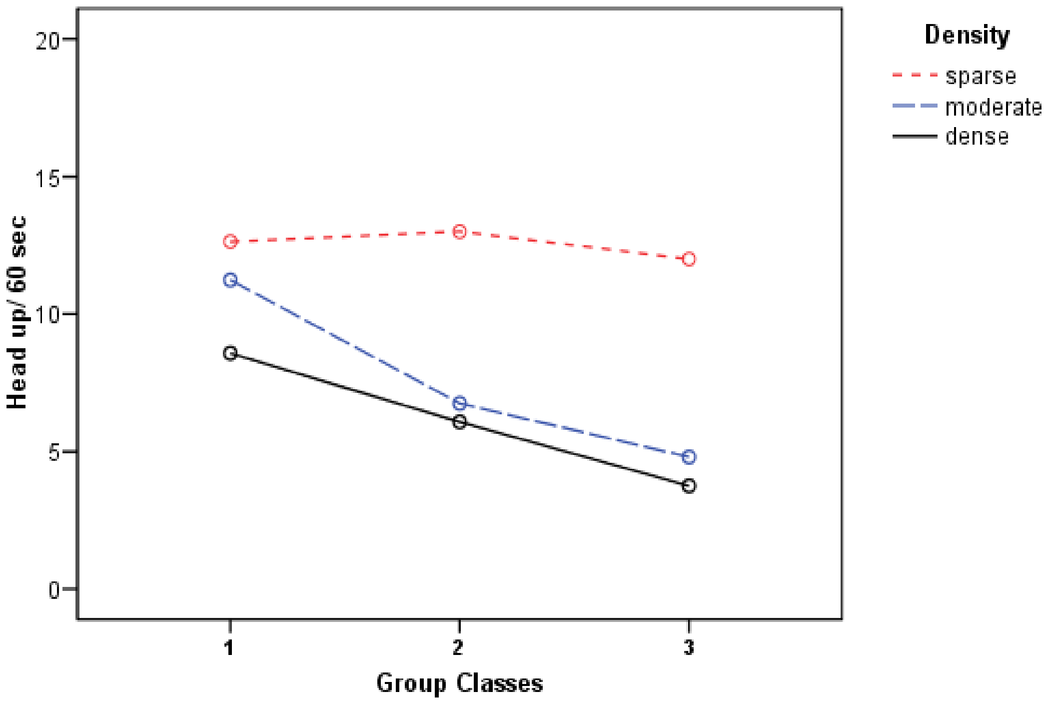


Figure 4.14 The Influence of density on scanning behaviour of crested larks foraging in winter season within the group size categories. Class 1: 2-3 (n=45), class2: 4-8 (n=26), class3: 9-13 (n=12) individuals. Density was classified according to spaces between individuals into sparse (≥1m apart), moderate (0.5-1m apart) and dense (≤0.5m apart). One way ANOVA, of head up on density categories F= 18.80, P-value<0.0001, (n=83), df= 2 and 80.

II. Summer season

4.2.4.2 Vigilance while roosting

During roosting in the middle of the day, the proportion of the group in a sitting position was highly correlated with group size (Figure 4.15).

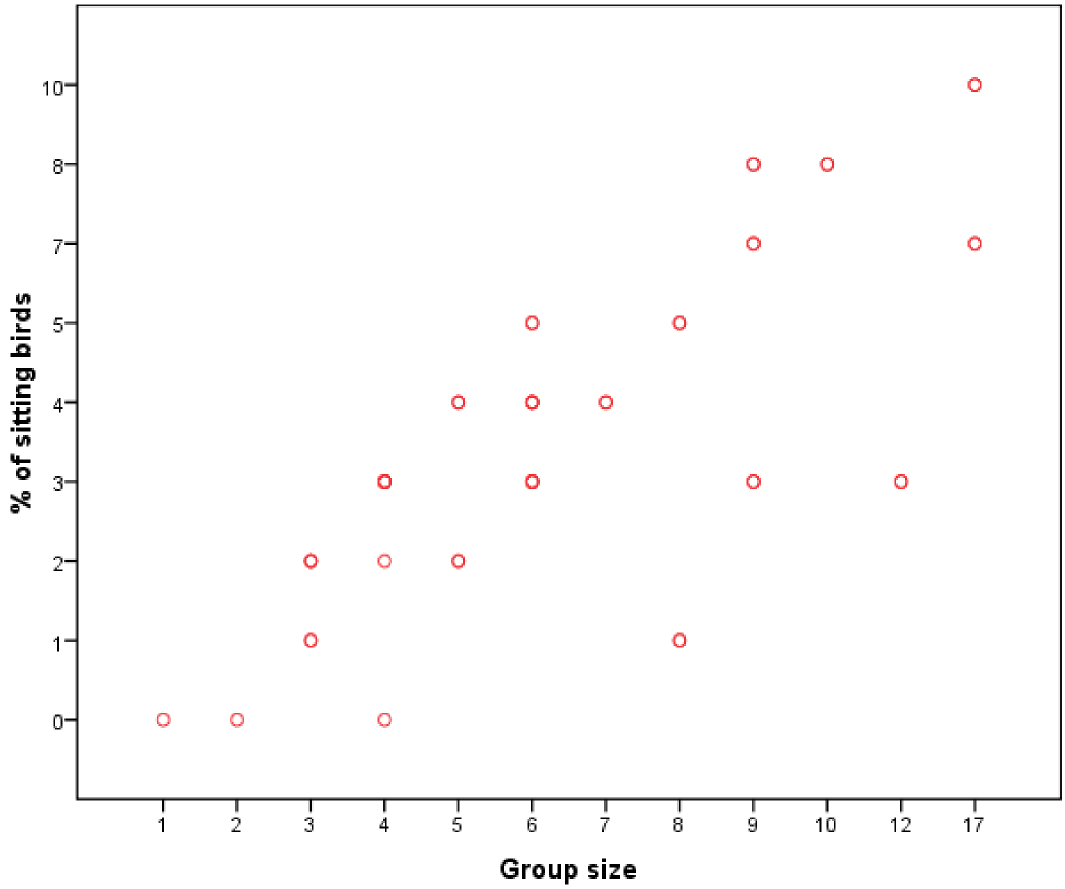


Figure 4.15 The relationship between group size and the proportion of sitting birds n=49. Some points on top of each other. Pearson correlation coefficient of number of sitting individuals with group size is 0.753, df =47, P value ≤0.0001.

4.2.4.2.1 Close eye ratio while in shade

The proportion of birds in a group that had their eyes closed varied with both group size and with the posture of the birds. Sitting individuals represent 44.63 % of birds across all group sizes (n=49), with the remainder being standing.

Large groups were found to have more birds with their eyes closed, but this effect was only present in the birds that were sitting down; for the standing birds, most birds had their eyes open, irrespective of group size (Figures 4.16)

Standing **Sitting**

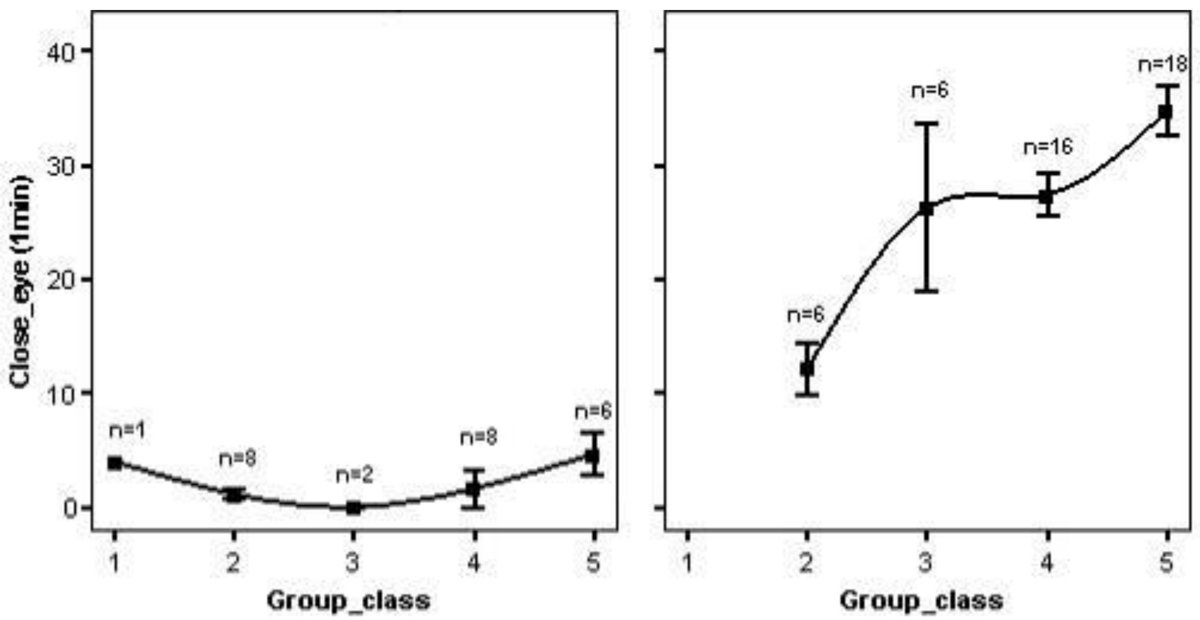
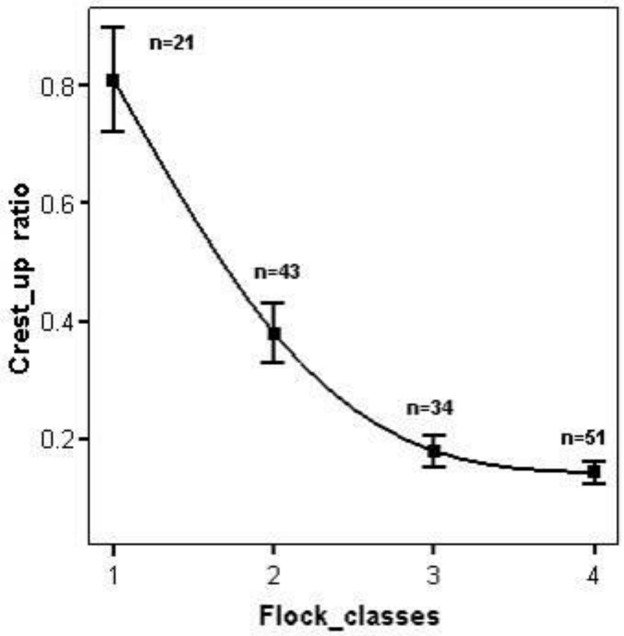


Figure 4.16 Mean number, and 95% confidence interval of closed eye duration time versus group size for sitting and standing birds. Group size was lumped into five classes; 1= (1), 2= (2-4), 3= (5-9), 4= (10-13), 5= (16-32). Single birds were always standing. For sitting birds df= 68, F= 71.259, P <0.001. No significant difference in standing birds.

4.2.4.2.2 Crest-up ratio while in shade

The proportion of crested larks with their crest in a raised position in roosting flocks also varied with group size, being lower in larger groups. Again, this was different for sitting and standing birds, with standing birds not being affected by group size, while in sitting birds, crest position was strongly affected by group size (Figure 4.17).

a)



b)

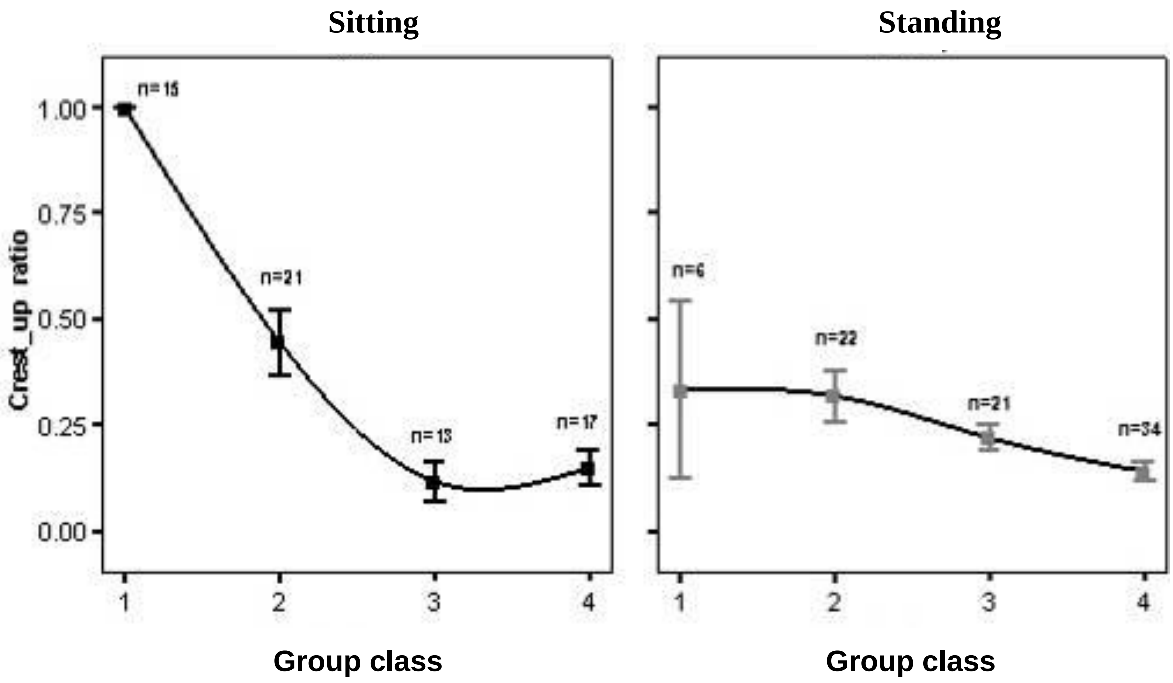


Figure 4.17 Influence of group size on the proportion of birds with raised crests. Group size was lumped into four classes; 1= (1), 2= (2-4), 3= (5-7) and 4= (8-35). a) All birds (n= 149), df= 3,145, F= 9.64, P< 0.0001. b) Birds are divided into two postures; sit (n= 66) and stand (n= 83). Four group size classes), df=3, 62, F= 28.547, P < 0.001.

4. Discussion

The data collected demonstrate the importance of the water hole and its structure for the bird community. Water holes are essential for many desert species in arid lands. But there is also a balance to be struck in the provision of shade around the water hole and predation risk.

Man-made waterholes should be introduced, but the design is very important. While deep water is suitable for some water birds such divers and large waders, it is unsuitable for many passerines such as lark species. Hence, the purpose of conservation and the species of interest should be considered. Talha water hole became an essential spot for the attraction of most biodiversity in the SAANR, especially in summer. It is important to regulate human disturbance by controlling visitor numbers and minimizing works in the water hole base. Establishment of some other water holes ringed by trees will increase the total water surface area and biodiversity richness.

Crested larks are social throughout the year, but their group size varies with season, generally being higher in summer. Variation in group size depends on time, location and behaviour. During early morning and late afternoon, individuals are actively looking for food and are scattered on open ground substrates, forming small group size. In the middle of the day, especially in summer, hot weather forces birds to drink water and sit in the shade. Therefore, birds aggregate around water holes and under shading trees.

The results of this study are consistent with the beneficial effects of being in groups reported generally (Pulliam 1973, Siegfried & Underhill 1975, Cresswell 1994 a, Lima 1994, Roberts 1996). I also found that in denser flocks, birds have more time for foraging. Hence, distance between foragers influences their social vigilance. Individual vigilance of crested larks declined with increased group size. This is consistence with other studies such as Elgar and Catterall (1981) who found that probability of detecting a predator increases with group size but individual scanning effort decreases. These data therefore suggest that, although crested larked do not regularly occur in flocks, when they do collect round a common resource, they obtain the anti-predator benfits commonly associated with larger group size.

In this study, flock size of crested larks was similar to Pulliam's (1973) study on finches during foraging, but the scanning rate of crested larks was much higher than finches. Average head up rate of a solitary crested lark was 18 scans/min compared with 12 scans/min for a single finch. And a flock of four individuals had 7 scans/min and 3 scans/min for crested larks and finches respectively. This may partly relate to scan duration which is just one second or less in crested larks, while it was two seconds in finches. Also, predator characteristics and abundance, habitat quality and human disturbance may vary between those two studies. Hence, how much time a fast predator, e.g. sparrow hawk, needs to catch a prey is very short. Hart and Lendrem (1984) assumed 10 seconds for a moderate fast predator to make a final unconcealed approach and strike a prey.

The approach of a sparrow hawk toward a flock of crested larks is more risky than that of a desert monitor *Varanus griseus* approach (See Section 1). Avian predators often use random attacks while ground predators use prey behaviour to time an attack e.g. lions use check-wait and double-check wait tactics to launch attacks with first or second head down when an ostrich is foraging (Hart & Ledrem 1984). Furthermore, ambient temperature and time of day may influence prey response toward a detected predator; whereby a prey keeps looking and scrutinizing the detected predator for a period before responding (Elgar 1989). Global Raptor Information Network (2010) cited Geilikman (1959) states that sparrow hawks often catch prey passing nearby while sitting on a tree and also fly from tree to tree to flush passerine birds and then try to capture them in openings between trees. Thus, vegetation density is very important.

Elgar (1989) pointed out some potential confounding effects on vigilance of factors such as age and sex. But it was not possible to examine this in my study since the birds are monomorphic and their age was unknown.

Large group size has costs, such as increased food competition and being a more conspicuous target for predators. Cresswell (1994b) found that larger flocks of skylarks were more often attacked by predators. But, a predator captures one prey during an attack usually (Li *et al.* 2009). Hence, a skylark individual has a lower potential risk of predation in larger than smaller group size due to the dilution effect per capita or the hypothesis of "safety in numbers". (Hamilton 1971, Keys & Dugatkin 1990).

Despite many arguments on group size effect on vigilance or anti-predator behaviour, most authors agree that cooperative vigilance is beneficial to individuals as demonstrated above in crested larks.

Conservation of avifauna requires considering their habitat ecology while planning for management of the environment. Hence, vegetation cover preference of avifauna species varies from family to another. Scattered and low shrubs vegetation around a water hole can provide shelter for crested larks while shading. However, aerial predators follow different tactics than ground predators. Thus, heterogeneity and spaced vegetation cover is preferred for crested larks to permit to have wide vision and recognize potential predators.

Crested larks were seen escaping the perch place of raptors especially sparrow hawks. The few individuals that remained in the area and did not escape with the rest, remain spaced about 3m from the sparrow hawk. Those individuals became highly vigilant. On the other hand, crested larks were less vigilance toward shrikes and desert monitor *Varanus griseus*. Hence, crested larks permit a closer approach of shrikes and desert monitors than sparrow hawks. In midday summer season, shrikes were seen about 1m spaced from crested larks within Talha water hole. Despite shrike predation on small passerines such as barn swallows and warblers, they were not seen chasing or trying to attack crested larks. Size and speed of shrikes reduce their threat to crested larks. Vulnerability of different species to shrike attack could be affected by several factors such as local knowledge, fatigue, dehydration, starvation, agility, camouflage, age and size. Desert monitors seemed very active during the middle of the day in summer, walking around the water hole and swimming in its water to chase small passerines perching on droopy tree branches near the water surface. Crested larks however permitted desert monitors to approach them till 1/2m while they are shading. The low speed of a desert monitor in comparison to a sparrow hawk may explain this response and less caution of crested larks.

Chapter 5: Thermal Challenge 1: Breeding behaviour

Abstract

Nests of territorial breeding larks were located in the main study areas in Kuwait during 2008-09. The larks studied in this part of my thesis were greater hoopoe lark, crested lark, bar-tail lark and black-crowned sparrow lark species. The territory size varies between species and individuals in different habitat types. A male monitors and guards his female while she constructs the nest, incubates and feeds nestlings. *Stipa*, *Stipocyprus* and *Haloxylon salicornicum* communities were the preferred natural habitats while barley and trefoil crops, especially adjacent to mounds of organic fertilizers, were the preferred agricultural habitats. Observed nests were 35 for crested larks, 3 for bar-tailed larks, but only 1 for black-crowned sparrow larks. Four territory areas of greater hoopoe larks during 2008 nest were seen. All nests in agricultural habitats belonged to crested larks (n=33, 90% of the nests in the study area). New crops of alfalfa and barley 20-30cm height were the main habitats for crested lark pairs; territory size was 0.5±.015 ha in the Pivot farm area. The breeding season was Feb-May in semi-arid areas, but it extended until end of June and probably more in the Pivot farm. Most nests were located on ground shaded by vegetation 30-60cm and 2-8m away from main roads. Nest site selection was correlated with specific plant species. Crested larks nested under suitable perennial plants such as *Haloxynemum sp.*, *Salsola sp.* in semi-desert areas. Grass formed the bulk of the nest material (N=10). Clutch size was 4±1eggs. Feral dogs appear to be the biggest threat to breeding success; they scavenged and predated nests and nestlings. Harvesting destroyed many nests (>14 nests). Few juveniles were seen in SAANR, whereas all breeding stages (eggs, chicks, fledglings, post-fledglings and juveniles) were seen in the Pivot farm.

Section 1: 5.1 Factors influencing nest distribution

5.1.1 Introduction

In arid or semi-arid ecosystems, many birds usually time their reproduction to coincide with high food availability (Dean *et al.* 2009). Rainfall often acts as a trigger for many desert birds (Dean *et al.* 2009), enabling them to breed when the availability of water and food resources is greatest (Dawson & Bartholomew 1968). Hence, they can avoid breeding in stressful periods of the year when solar radiation is high and water is scarce (Carey 1980).

Birds are relatively well studied, widespread creatures, so they can play an important role as natural indicators of habitat biodiversity, and can be considered as a robust gateway to protect these habitats (Evans 1994). Larks *Alaudadae* are resident passerine representatives of shrub steppe habitats (Laiolo & Tella 2006 a) and thought to possess a number of characteristics that enable them to be used as indicators of habitat integrity (Martin & Possingham 2005). Until recently, little was known about larks' habitat selection and nest site selection in Kuwait. Few larks can breed in this desert ecosystem; 11 species out of 15 European larks visit Kuwait during the migration seasons (see Table 1.1), but only four of them have been recorded as breeders (Gregory 2005).

Larks are mostly monogamous, open ground nesting birds (see Introduction) and defend a territory during the breeding season. In west Asia, particularly in the Arabian Gulf Countries, larks breed in summer from March to June. Mostly, the female is the incubator and the male is the territory defender while both parents care and feed the young (Cramp *et al.* 1988).

Lark habitat requirements vary from one species to another, but, generally, they are restricted more or less to sparse and short vegetation. Wintering skylarks *Alauda arvensis* in farmland prefer vegetation height from 1 to 10cm and ground cover ranging from 10 to 75% (Eraud & Corda 2004). However, uniform vegetation structure (i.e. from providing water to cattle in such areas) is known to affect densities, for example as recorded in lark buntings *Calamospiza melanocorys* and horned larks *Eremophila alpestris* (Fontaine *et al.* 2004). Therefore, heterogeneity of vegetation is important to their survival, and diversity of vegetation community types will influence habitat structure. Lesser short-toed larks and short-toed larks were found using different microhabitats for different behaviours (*Salsola* sp. for nesting, less cereal for feeding, and *Artemisia sp.* for singing). Hence, microhabitat preferences should be considered rather than simply overall natural vegetation cover to conserve steppe birds (Serrano & Astrain 2005).

Species abundance depends in particular on habitat type and vegetation structure; skylarks have been found to prefer arable lands with relatively low vegetation as macro habitats and whereas they prefer stunted growth such as shallow depressions, cultivated plots and edges of narrow tarmaced farming roads as microhabitats; therefore, this stunted vegetation growth should be constructed or at least preserved (Schoen 2004). Donald and Morris (2005) consider creating plots and small rectangular patches of bare ground within autumn-sown cereals appear to provide the benefit of spring-sown cereals at very low costs. They found skylarks produce more chicks in fields with these kinds of plots than in those without. On one farm in southern England, the skylark population more than doubled after the introduction of such skylark plots (Donald & Morris 2005).

This chapter is concerned with how birds cope with the thermal challenge posed by such a hot and arid environment as is found in Kuwait. I first tried to quantify what the challenge was by examining temperature fluctuations in a range of real and artificial nests. The thermal challenge in different nest positions was quantified by using data loggers. This helps explain choice of habitats, nest position and timing of breeding since the challenge is reduced in vegetation and early in the season.

Individual distribution pattern is a consequence of behavioural decisions. Many factors such as predator avoidance, shelter from weather and food quantity play a role in determining habitat preferences (Robinson & Sutherland 1999). The geographical range of species varies, e.g. the crested lark has a much wider range than desert larks, and while the latter is strictly a desert species, crested larks inhabit both desert and non-desert regions. Even though both species share most seed types, and they forage within the same habitat, crested larks have broader niches and higher temporal fluctuations in niche breadth than desert larks (Shkedy & Safriel 1992). However, the same bird species can show different distribution patterns according to local habitat structures and density of breeding individuals.

b) Breeding

Most temperate zone passerines produce at least one clutch of eggs every year, whereas other small desert birds (e.g. greater hoopoe larks) may skip a breeding season in certain environmental circumstances (Tieleman *et al.* 2005). Spring-summer breeding in low latitude regions, where the temperature is high and little food is available, demands high effort from parents during the incubation period. Reproduction and survival opportunity may be constrained by the amount of time, water and energy that parents can allocate to rearing offspring, e.g. greater hoopoe larks *Alaemon alaudipes Desfontaines* in Saudi Arabia were found feeding their offspring 55 times per day and shaded their chicks about 5 hours per day to protect them from solar radiation (Tieleman *et al.* 2003).

Territory size correlates negatively with vegetation diversity (Jenny 1990), habitat quality and population density (Beason & Franks 1974, Beason 1995). It varies according to individual qualities (Mickey 1943). Earlier territories of horned larks are larger and decrease in size with time as the breeding season proceeds and as additional males move in to a breeding area (Mickey 1943). In high latitudes, the territory size of a horned lark was considerably larger about 2.3-5.1ha in Cape St. Mary's, Canada (Cannings & Threlfall 1981), whereas it was small in grasslands 0.3 ± 1.4ha in Colorado, USA (Boyd 1976) Similarly, the territory size of the crested lark in high latitudes has been found to be substantially larger - about 5-15ha in eastern Franconia, Germany (Gubitz 1982) and 5-15 ha in Bayreuth, Germany (Gubitz 1983), whereas it was small in grasslands 0.58 ± 0.16 ha in Denmark (Moller 1985).

c) Nesting

The nesting microhabitat of species varies with breeding region and seasonal conditions. For example, the crested lark which breeds in the warmest months of the year, preferred artificial nest boxes provided in the most wind-protected locations on roofs (shelter and protection from South and Southwestern direction in Hungary) and such areas are at the same time also the driest (Orban 2004). The horned lark *Eremophila alpestris* prefers a more northerly nest position, which has been shown to offer multiple advantages for regulating the nest microclimate in northeastern California (Hartman & Oring 2003). On the other hand, an analysis of habitat characteristics showed that wood larks select their breeding site carefully; their territories were found to be large and open in Southwest Finland (Valkama & Lehikoinen 1994).

While horned larks nest in sparse cover and are relatively exposed, the lark bunting *Calamospiza melanocorys* nests beneath shrubs, on the leeward side of shrubs, or on clumped grasses. As the lark bunting breeds in later season than the homed lark, it is exposed to higher ambient temperatures and decreased winds. Male lark buntings assist the female with incubation, and their black plumage provides an opportunity for radiative cover (With & Webb 1993).

This part of my study aims to examine: 1) the presence of lark nests in protected and non protected areas in Kuwait, 2) the quality of nest habitats, 3) the factors influencing the distribution of nests and 4) the macro-habitat characteristics of nests.

5.1.2 Method

Study area and Species

The study was carried out in Kuwait during 2008-09. It involved five areas: 1)Sabah Al Ahmed Natural Reserve (SAANR) 330km^2 protected area (PA); 2) Kabd Research Center (Kabd), 40km^2 (PA); 3) Behind SAANR, 80km^2 non protected area (NPA); 4) Right Kabd, 80km^2 (NPA); and 5) The Pivot farm, 8km^2 an agricultural area was survived only in 2009 (Figure 5.1).

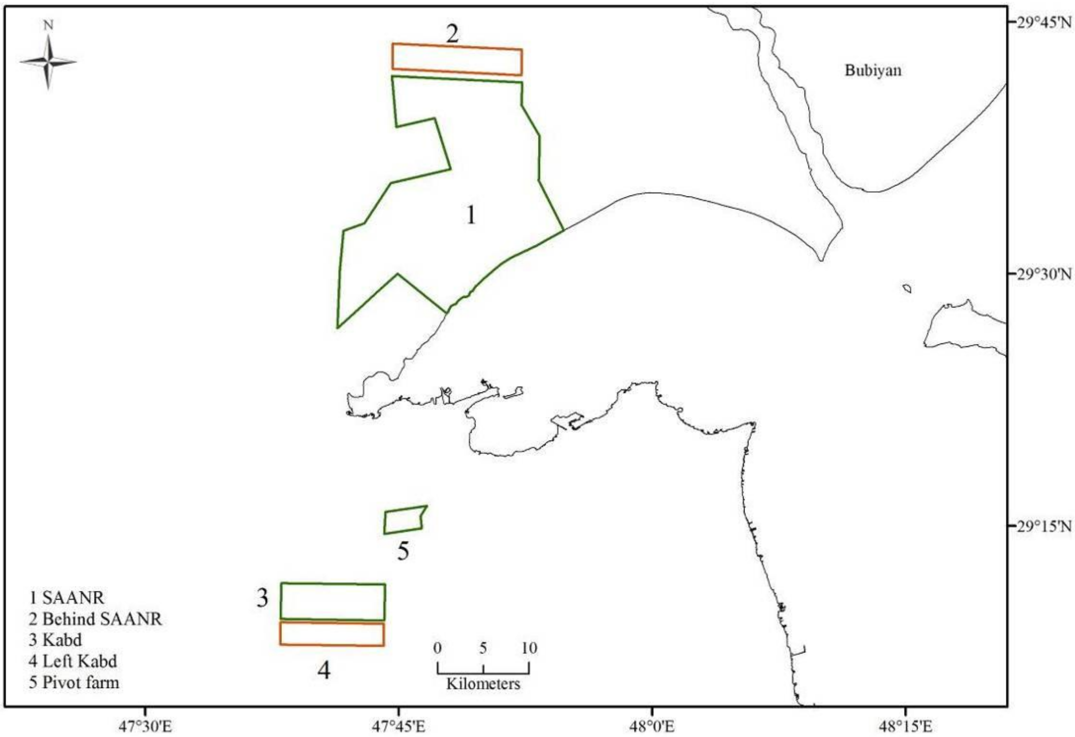


Figure 5.1 Kuwait Map; 1 SAANR (PA), 2 Behind SAANR (NPA), 3 Kabd (PA), 4 Left Kabd, 5 Pivot farm

Data collection

I examined nest distribution and territory areas of breeding larks. The species were greater hoopoe lark *Alaemon alaudipes*, crested lark *Galerida cristata*, bar-tailed lark *Ammomanes cincture* and black-crowned sparrow lark *Eremopterix nigriceps* all of which are territorial species.

All five areas were surveyed continuously by two visits per week from February to July to examine presence of nests or territories in 2008-09 except the Pivot farm, which was visited only in 2009.

The larks' breeding behaviours (e.g. display, singing and other courtship behaviour (song-flight, rising with rapid wing-beats and hovering around a particular site) were monitored throughout March-July through survey routes. Presence of pairs, singing males defending areas against the same or different species and courtship displaying birds were taken as indicative of territory occupation (Nice 1933 and Mayr 1935). In addition, the distance to the nearest neighbouring male was recorded as an indicator of the density of crested larks. Furthermore, the edge of alfalfa *Medicago sativa* and barley crops also used to estimate the border of a territory. This gives a rough estimate of territory size only and when I used the nearest neighbour distance I split the distance between the two nests equally.

Each area was subjected to two visits weekly from 15 February to 15 July for data collection, as in Bibby *et al.* (1992). I recorded active territories on the basis of the behaviour of the birds, but I did not always locate the nest itself. Observations were done by using a vehicle as a hide. Nests were sought in the daytime from dawn to midday. In crop fields, presence of nests in unreachable sites or dense vegetation was confirmed by watching females' behaviour (transferring nest material or carrying food to the specific site several times) and males' behaviours (monitoring the area and performing anti-predator behaviour).

Macro and micro-habitat of nests were examined. Location of a nest, type of the shelter plant, height of the plant and the nearest road to the nest were observed. Depth of the nest, its diameter and the thickness of lining layer were measured. In addition, composition of the nest material was examined in a sample of 16 crested lark nests.

Territorial defence behaviour of males was monitored to estimate the territory area (Verbeek 1967, Beason & Franks 1974 and Cannings & Threlfall 1981). A potential territory area was visited frequently up to seven times to determine the size of a territory. Eggs' measurements (clutch size, length, width and weight) were recorded for any observed nest containing eggs. Fledged young or juveniles were recorded as an indicator of a successful nesting attempt.

5.1.3 Results

1. Nest presence in protected and non protected areas

The numbers of active lark territories found in the different areas in 2008 were as follows; in SAANR, Kabd and Pivot 7, 1 and 33 nests respectively (Table 5.1). The breeding season within SAANR and Kabd in year 2009 was worse than in 2008. No active lark territories were seen in either area in 2009. The 2008 territory areas of greater hoopoe larks in SAANR were found empty and lacked any breeding indications such as courtship display during the whole breeding season during 2009. Active territories only occurred in SAANR 2008 and Pivot 2009. In the two non-protected areas, Behind SAANR and Right Kabd no active lark territories or nests were located in either 2008 nor 2009.

Table 5.1 Active territories of larks during 2008-09

Species \ Area	SAANR		Kabd		Pivot
	2008	2009	2008	2009	2009
bar-tailed lark	3	-	-	-	-
black-crowned sparrow lark	-	-	1	-	-
crested lark	-	-	-	-	33
greater hoopoe lark	4	-	-	-	-

SAANR territories belonged to greater hoopoe larks and bar-tail larks; four distinct territories for greater hoopoe larks and three nests for bar-tail Larks. Territory areas of greater hoopoe lark were plain sandy habitats, dominated by *Stipagrostis plumosa* grass and sparse *Haloxynemum* shrubs and about 300X100 meters (3 hectares). Greater hoopoe larks were observed protecting their territories until June by frequent songs, physical displays and courtships within and on the border of these sites. They showed courtship display and mating, but the nests themselves were not located. On the other hand, bar-tailed larks inhabited remote ridges, gravel areas dominated by *Stipagrostis plumosa* grass. *Stipagrostis plumosa* species was the plant shelter for bar-tail lark nests (n=3). They did not defend such large territories as greater hoopoe larks, but instead appeared to protect only the immediate nest areas. When a predator such as a human approaches the nest location the male flies to warn the female without releasing any type of call. In contrast, the greater hoopoe lark attacks a human observer continuously and repetitively and even snakes while he/it was trying to approach the nest.

Over ten months in 2008, greater hoopoe larks were present in the same habitats with little shift, which means they are permanent residents in this protected area throughout the year. Other sites visited, both protected and non protected in Kuwait, were devoid of greater hoopoe larks.

Until mid summer, June, two greater hoopoe larks inhabited their specific territories. In July and August, only one male was shown in his area, but he was not seen later on during September and early October.

In August, September and October greater hoopoe larks were not seen any more in their previous territories during early or late morning. They fly away looking for food wherever it is available, when their territories became unsuitable for foraging. Two territories were deserted one month earlier than the rest. As the breeding season ceased, greater hoopoe larks became unrestricted to their territories or at least did show any defence behaviour.

In Kabid, only one active lark territory was recorded, and this was of the black-crowned sparrow lark. However, later dozens of juveniles were seen gathered around the waterhole (see Chapter 4) to drink in May 2008. These were probably bred in neighbouring farms and came to Kabd after the post-fledging stage.

In 2008 the Pivot farm was not surveyed. But, in 2009 the Pivot farm was rich with crested lark nests where 33 active breeding territories were identified. 12 nests of those active breeding territories were located. Territory size of crested larks in the Pivot farm was 0.4 ± 0.15ha.

In view of the fact that crested larks are a monomorphic species it is difficult to determine the number of males and females. However, I expected to find at least 5 nests in Kabd and 20 nests in SAANR. This estimation was based on the number of crested lark pairs encountered (5 pairs in Kabd and 20 pairs in SAANR) foraging and flying together during the breeding season where some also showed some courtship display in SAANR. Unfortunately, nests were not seen in neither Kabd nor SAANR.

In the non protected areas B-SAANR and R-Kabd no nests were expected to be found due to the very low number of crested larks seen and no pairs were seen foraging together or behaving as pairs there. In addition, neither B-SAANR nor R-Kabd has a suitable habitat for crested larks to breed. Both of those areas were devoid of shrubs and patches to attract crested lark to inhabit or nest.

2) The distribution of territories in relation to vegetation type in the Pivot farm

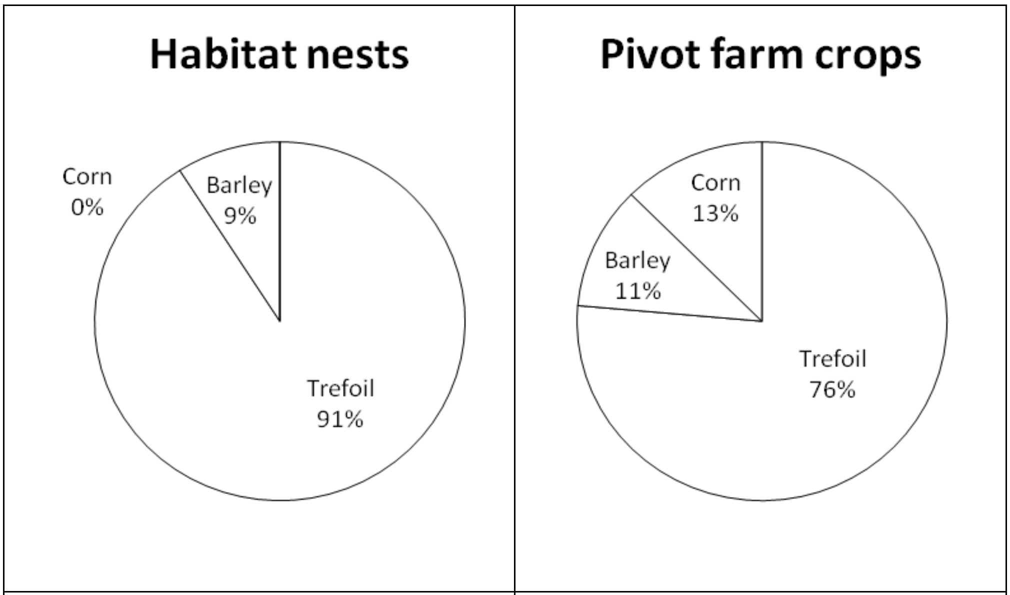
There were sufficient nests in the Pivot farm area to examine factors influencing nest distribution. Figure 5.2 shows the farm area. Presence of permanent fresh vegetation cover accompanied with organic fertilizers and irrigated water in the Pivot farm attracted numerous crested larks. Alfalfa formed the dominant favourable habitat for crested larks followed by barley crops (Table 5.2). Figure 5.3 shows the proportional vegetation cover in the farm and the proportion of nests in these different vegetation areas.

Figure 5.2 The Pivot farm image, green circles represent crops mainly alfalfa. Those circle crops watered by automatic rotated irrigated system. Other planted trees such as small palms and small olive trees watered by irrigation pipelines, Google Earth 2010

Table 5.2 Distribution of crested lark nests in the Pivot farm

Corn	**Barley**	**Alfalfa**	**Habitats**
12.5	11.1	76.4	**Area %**
0	3	30	**Number of Nests**
4.1	3.7	25.2	**Expected Number of Nests**

The value of Chi squared equal to 5.16, with 2 df, and the P value<0.01.



b) Percentages of nests within habitats.	a) Percentages of occupied habitats (hectares).

Figure 5.3 Percentage of habitats and nests' distribution of crested larks in the Pivot farm

3) Nests in the Pivot Farm

In comparison of 33 active territories of crested larks in the Pivot farm, 12 nests were located and examined. Most territories were in alfalfa crops (n=30) while few in barley crops (n=3). All those nests were found on the ground under vegetation cover alfalfa and barley (n=12) in the Pivot farm (Figure 5.4). Vegetation cover type varied from area to another and from one nest to another.

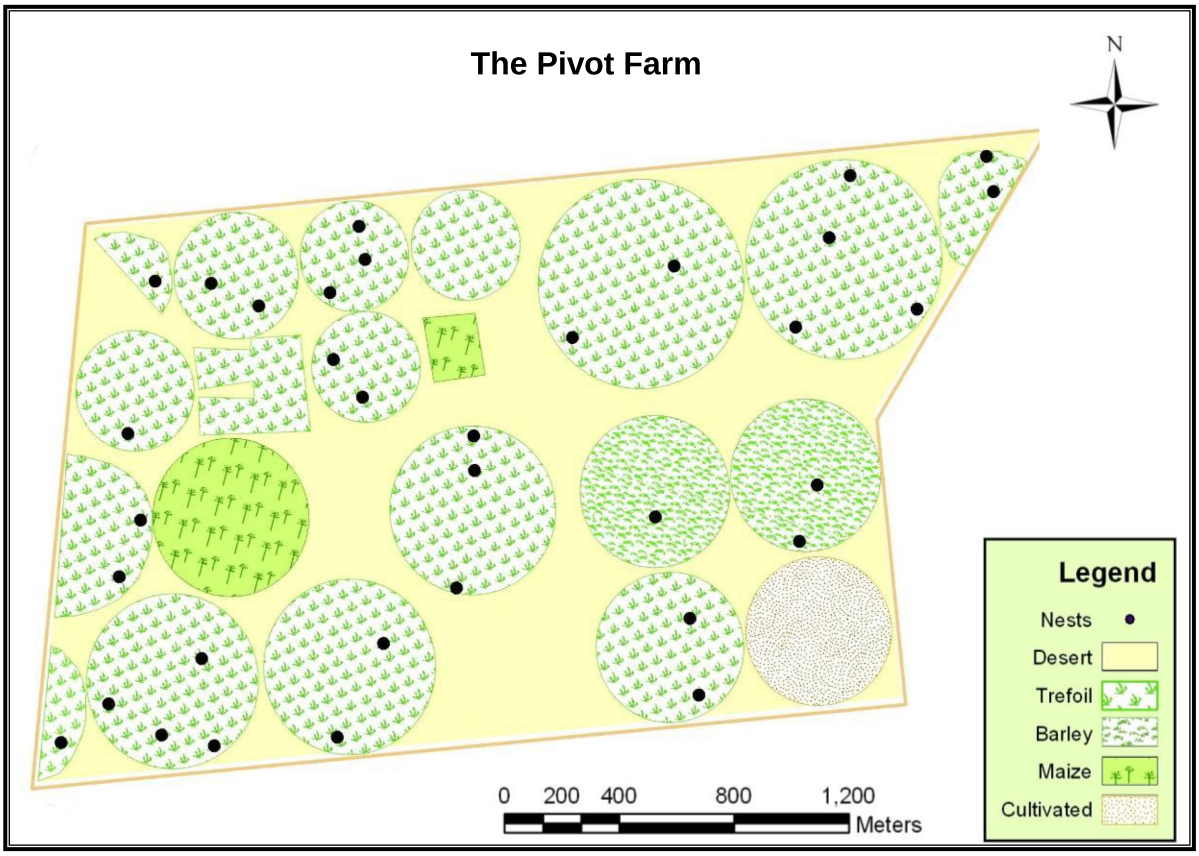


Figure 5.4 Habitat and nest distribution of crested larks in the Pivot farm

New crops 20-30cm in height were preferred habitats for crested lark pairs to mate. The specific mating behaviour of crested lark males was seen on different territories (N=10). The male flutters and sings for 3-5min at a height of 40-50m then drops down vertically from the sky to mate with his female.

The clutch size of crested larks was 4 ±1eggs (N=14). Average egg length was 22.7 ±2mm (or 23 ±2mm) and its width was 16.2 ±0.2mm (or 16 ±1mm).

The breeding season was Feb-May in semi-arid areas, but it extended until the end of June and early July in the Pivot farm due to presence of vegetation crops and water irrigation. However, these late nests were few in number (n=3) and had small clutch size 2 eggs (n=2) and 3 egg (n=1) compared to Mar-May nests (n=30) which had a clutch size of 3-4 eggs. Furthermore, they are less successful as the breeding season proceeds, where temperature rose up to 42°C in nest and 70°C in exposed area (see Ch 5, section: 5.2 Nest position and nest temperature). In such circumstances, incubation becomes very costly. Hence, parents were forced to abandon their nests (n=3) in the Pivot farm. Also, predation risk increases proportionally with an increase of temperature as lizards and snakes appear and become active.

By July, few pairs were thought to have active nests. Most crested larks did not seem to be in pairs or to be defending territories. Furthermore, their behaviour style changed (they foraged and shaded in groups 3-5 individuals). This alteration of behaviour was a confirmation of the end of the breeding season.

4) Micro-habitat characteristics of nests

All crested lark nests in the Pivot farm (n=33) were located on the ground shaded by vegetation 30-60cm. Crested larks tended to nest alongside roads. All nests were found 1-8m away from main roads; the average distance from a road to the nest was 1.8 ±0.3meter (see Figure 5.4). Grass formed the main nest material (N=12). Nest materials were totally grass in the Pivot farm (N=12). Crested lark nest dimensions were: 4.2 ±0.1cm depth, 67.4 ±6.0cm diameter and 16.3±0.8cm thickness. Harvesting destroyed many crested lark nests (>14 nests out of 33 nests) in the Pivot farm.

In addition to the Pivot nests, in SAANR four territory areas belonging to greater hoopoe larks were identified. Their territories were sandy habitats dominated with *Stipagrostis plumosa* grass and *Haloxylon salicornicum* shrubs, except one territory which was totally dominated by *Haloxylon salicornicum* shrubs. Hence, greater hoopoe larks appear to prefer sparse vegetation cover to have access for foraging and escaping from predators. In spite of dense vegetation cover in the coastal area of SAANR, greater hoopoe larks were not attracted to this habitat. Also, they were absent in ridges area where land topography involves substantial slopes.

5.1.4 Discussion

Absence of nests and signs of breeding in non protected areas: B-SAANR and R-Kabd were correlated with their poor habitat quality (Chapter 2; vegetation cover). Hence, nests only occurred in protected areas and the arable land. Presence of nests was associated with the vegetation cover. Plants provided suitable shade for a nest and a nester during incubation. Plant shelters were perennial shrubs in protected areas, and short crops in the arable land.

In Saudi Arabia, crested larks nested under *Haloxylon salicornicum* (n=3) and *Salsola imbericata* (n=1) species in open range land and under pumpkin (n=1) in an arable area while greater hoopoe larks nested on *Haloxylon Salicornicum* (n=4) (Alshehabi 2009). Nests of crested larks in open land areas in Saudi Arabia were formed by a bulk of wool and grasses accompanied with little cotton or plastic threads (N=4) (Alshehabi 2009). This is similar to what I found in my study.

Absence of crested lark nests in SAANR and Kabd is a sign of overgrazed poor habitat ecosystem. Shortage of rainfall during 2008-09 affected the breeding of larks negatively. These two breeding seasons were characterized by dryness of perennial shrubs and scarcity of annual plants. In addition to rainfall shortage, hunters invaded Kabd, especially in the breeding season, destroyed habitat, and killed and disturbed adult crested larks.

Only 4 juvenile of crested larks were seen in SAANR during late spring and early summer around Talha water hole while drinking water. On the other hand, all breeding stages (eggs, chicks, fledglings, post-fledglings and juveniles) were seen in the Pivot. Black-crown sparrow lark bred in Kabd where juveniles were photographed around a water hole at May 2008. Greater hoopoe larks and bar-tailed larks did not show any sign of breeding success 2008-09. Absence of their juveniles around Talha water hole (see Chapter 4) was a negative sign of their breeding success in SAANR. The Pivot farm possessed potential characteristics that are absent in open areas and protected areas. Firstly, it is surrounded by hedges which improve the microclimate by reducing wind and dust storms. Secondly, presence of fresh crops especially alfalfa and barley throughout the breeding period is important since this will influence food availability. Thirdly, a continuous irrigated system for crops reduces the temperature of nest micro and macro-habitats, especially in the midday during midsummer. Fourthly, irrigation systems supply larks with water to drink or cool down their body temperature. Fifthly, security restrictions to enter the Pivot farm make it a semi-protected area, at least for some bird species.

Crested larks were more abundant in alfalfa crops than in barley, the later grows faster and has fewer gaps between plants. Hence, the texture of alfalfa may be favourable to crested larks, where they can forage, interact and get some sunlight. Texture of alfalfa crops includes spaces, which facilitate larks' movements to forage, shade and hide. In addition, it helps them to conceal themselves and their routes to make the nest locations ambiguous. On the other hand, barley does not permit easy movement for foraging or cryptic purposes.

Territory size of crested larks in the Pivot farm was 0.4 ± 0.15ha. This is close to Moller (1985) results 0.58 ± 0.16 ha in Denmark. Furthermore, the territory size of crested larks in the Pivot farm was ten times smaller than Gubitz (1982) results 5-15ha in eastern Franconia, Germany. This variance in territory sizes of crested larks can be a response to their breeding vegetation cover and habitat ecology. Hence, territory size correlates negatively with vegetation diversity (Jenny 1990) habitat quality and population density (Beason & Franks 1974). The small size of territory in the pivot can be referred to the texture of alfalfa and barley crops. Dense alfalfa and barley crops permit plenty of shaded spaces for crested larks to forage and reach their nests from different entrances and distances under leaves. This type of crop texture makes the identification of nest location tricky and reduces interferences between different pairs which did not demand a large territory size in comparison to other scattered vegetation cover in non agricultural habitats. However, within agricultural habitats the territory size of crested larks may vary due to crop types and density of vegetation.

Spring 2009 was worse than 2008, with less rainfall and more dry plants cover generally. Kabd was devoid of greater hoopoe larks during 2008 and 2009. In 2009, Pivot farm was surveyed during winter and spring and also no greater hoopoe larks were seen. These areas may not possess suitable habitats for such species. Predators in SAANR, Kabd and Pivot were foxes, snakes, raptors and dogs. Free dogs represented a high threat to breeding success in the Pivot; they were observed scavenging in nest habitats and predating nest and nestling throughout the day.

This study reveals the challenge that larks face to breed in Kuwait. To breed, a suitable secure habitat is a mandatory demand. Habitat degradation was a remarkable sign of most non protected areas in Kuwait. Crested lark were found mostly nesting in arable lands to compensate for poor habitat quality, weak vegetation cover and rain shortages in protected areas. But, greater hoopoe larks and bar-tail lark did not inhabit or breed in arable lands. When habitat degradation coincides with rain shortage, this will deprive greater hoopoe larks and bar-tail larks from breeding. Consequently, they may face potential physiological extinction due to their incapability to breed or unsuccessful breeding attempts.

My results confirm that local farming management is important to protect grassland bird abundance (Batary *et al.* 2007). Presence of high biomass soil invertebrates, e.g. larvae of earthworms, due to dung in managed grassland fields (Atkinson *et al.* 2002) encourages crested larks to breed.

Section 2: 5.2 Nest position and nest temperature

5.2.1 Introduction

Oviposition sites are assumed to be adaptive i.e. to provide fitness benefits (Lloyd & Martin 2004, Yanes & O'Nate 1996). The placement and position of bird nests differs among species and in different environments (Greeney 2009). Location and position of nests may be influenced by many factors such as parental behaviour (Grazhdankin 1992), vegetation cover (Nelson & Martin 1999), thermoregulatory requirements (Herranz *et al.* 2004), security of nesting sites (Khoury *et al.* 2007), degree of shelter from weather (With & Webb 1993), and predator avoidance (Burton 2006). Optimum nest position can vary at different times of day or season, and compromise may be necessary. For example, in open nesters, nests may be constructed to face prevailing winds during the day and avoid them in the evening (Hartman & Oring 2003). Small ground nesting species may change their nest position as the breeding season proceeds and temperature increases (Burton 2006). Greater hoopoe larks *Alaemon alaudipes* build their nests on the gravel plain away from vegetation early in the breeding season, then at the base of bushes and then above ground in bushes as the season progresses; this helps them to cope with thermal environment forces (Tieleman *et al.* 2008).

In semi-arid areas, sunlight and nest predation are selective pressures determining nest microhabitat selection (Yanes & O'Nate 1996). Cooling or warming nests to maintain optimal microclimate will affect parental time and energy budgets. Reproduction and survival may be constrained by the amount of time, water and energy that parents can allocate to rearing offspring in such environments. Spring-summer breeding larks (*Alaudidae*) in low latitude regions, where the temperature is high and little food is available, demands high effort from parents. Greater hoopoe larks *Alaemon alaudipes desfontaines* in Saudi Arabia were found feeding their offspring 55 times per day and shaded their chicks about 5 hours per day to protect them from solar radiation (Tieleman *et al.* 2002). Nestling growth and fledging weight of lesser short-toed lark *Calandrella rufescens* and thekla lark *Galerida theklae* are greater when the nest faces specific directions (Yanes *et al.* 1996).

Nest placement also has consequences for predation risk on both eggs and incubating parents (Tieleman *et al.* 2008). Predation rates may be as big a threat as habitat alteration (Whittingham & Evans 2004). While horned larks nest in sparse cover and relatively exposed sites (13% shaded in midday), the lark bunting nests beneath shrubs, on the leeward side of shrubs, or on bunch grasses (40% shaded in midday). As the lark bunting breeds later in the season than the horned lark, it is exposed to higher ambient temperatures and decreased winds. A male lark bunting assists the female with incubation, and its black plumage provides opportunity for radiative cover (With & Webb 1993).

Closely related species of larks can differ in their nest site requirements. Microhabitat preference for nesting sites differs between two sibling species of larks, the lesser short-toed *Calandrella rufescens* and the short-toed lark *Calandrella brachydactyla*. In Kuwait, the former nests in areas with greater percentages of short *Suaeda* plants and bare ground, while the later nests in areas with greater percentages of short *Salsola* plants (Serrano & Astrain 2005). The crested lark *Galerida cristata*, which breeds in the warmest months of the year, prefers artificial nest boxes provided in the most wind-protected locations on roofs (shelter and protection from South and Southwestern direction in Hungary) and such areas are at same time also the driest (Orban 2004). The horned lark prefers a more northerly nest orientation, which offers multiple advantages for regulating the nest microclimate in northeastern California (Hartman & Oring 2003).

In this part of my study, I investigated the consequences of variation in nest position for the thermal environment to which breeding larks will be exposed during incubation.

5.2.2 Methods

Study areas and species

This study covered selected open and protected rangelands in north and west of Kuwait during 2008-09. Selected areas were two protected (SAANR, 330km^2; Kabd, 40km^2) and three open (behind SAANR, 80km^2; left Kabid 40km^2; Pivot farm “arable”, 8km^2 (see Figure 5.1).

I explored lark breeding habitats throughout the breeding season Feb-June 2008-09. I noted the site location, position, adjacent plants, vegetation height, soil and plant community at each nest site. Lark nest positions were described in relative to the shading shrubbery (i.e. east, northwest, etc).

Because there were few reachable real nests to study, and also the potential disturbance and elevated predation risk that could result, I also used pseudo-nests placed at different locations and positions to mimic natural sites. Pseudo-nests were made of halved coconut external shells lined with grass layers similar to a real failed lark nest (Figure 5.5). The use of the shells held the material in place and was useful for comparing temperature at different types of nest sites. They were placed in shade under drooping shrub edges facing North, Northwest, Northeast, West, East, and South and exposed to sunlight. Shrubs of almost similar size and tall were chosen. To test the effect of nest elevation, I recorded the temperature of real incubated and non incubated palm dove and collared dove and real non incubated house sparrow nests for comparable data on ground and tree nests.

Figure 5.5 Pseudo-nests were made of halved coconut external shells lined with grass layers have similar air circulation to a real failed lark nest.

Data collection and analysis

I recorded the temperature of 17 real and 75 pseudo-nests by using Gemini Tiny Tag Data Loggers 2.2. The probe of the data logger was inserted into the nest up to 1cm from the inner base of an incubated or non incubated nest in order to be in the similar site of eggs in a nest. These data loggers recorded nest temperature every 5min for 12hrs daytime. To take into account effects of ground or soil location, I moved the pseudo-nests several times. Synchronized temporal measurements were done for pseudo-exposed, pseudo/real shaded and pseudo/real dove nest temperatures in semi-arid and arable lands.

Environmental temperature charts were compiled. Usually, the incubating bird keeps nest temperature steady (stable), but when air temperature exceeds bird body temperature, this becomes difficult and risky.

5.2.3 Results

Temperature of 92 nests was measured. 75 pseudo nests (different positions and exposed ground nests and vacant house sparrow nests) and 17 real nests (7 lark nests and 10 dove nests) were monitored for 24 hrs. I found lark nests generally to be at the base of shrubs or under them (n= 16). The exception was one greater hoopoe lark nest on a shrub or on ground away from neighbouring shrubs facing skywards without any vegetation shade. Bar-tailed larks nest next to the base of shrubby grass *Stipa* with about 50% of shade. Crested larks nest under several types of shrubs, grass and crops to get 50-80% foliage shade and possibly 100% in arable areas. Lark nest orientations were facing east (n=5), northwest (n=3) and west (n=2). East facing was commonest in the early breeding season, whereas northwest and west positions were later.

Pseudo-nests showed that the northeast orientation provides the less fluctuating temperature for ground nests during the breeding season March-May (Figure 5.6-5.7).

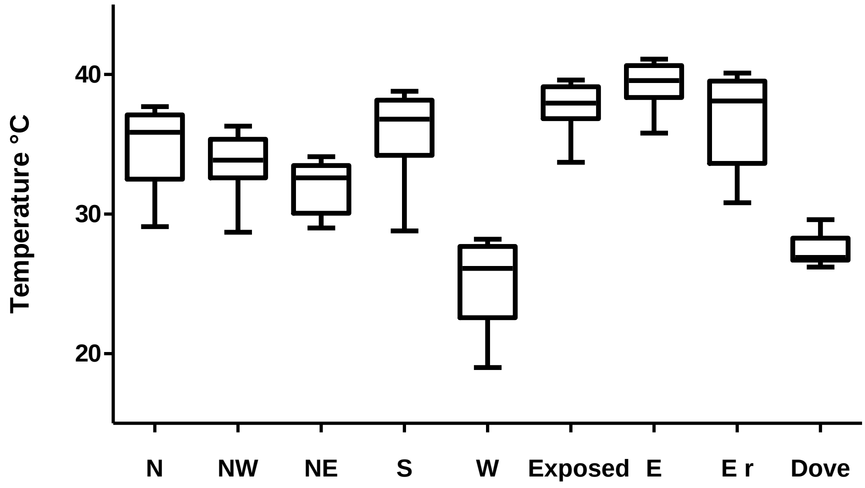


Figure 5.6 Box plot of temperature in pseudo-nests with different shelter and position during March 2009. Different position of nests N: north, NW: northwest, NE: northeast, S: south, W: west, E: east, E r: east rock and Dove nests. Four types of shelters were distinguished: (a. adjacent to stipa: grassy small shrub, b. exposed: without shelter, c. under rocks which shade the nest and d. tree dove nest). One way ANOVA comparison between the positions was significant P-value < 0.0001, F= 99.9 and df =8, 207.

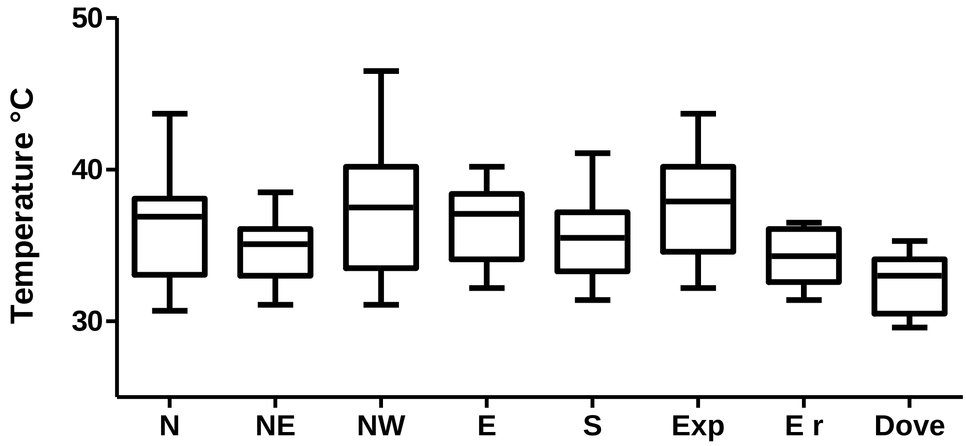


Figure 5.7 Box plot of shelter and position effect on temperature in pseudo-nests during early May 2009. Different position of nests N: north, NW: northwest, NE: northeast, S: south, E: east, E r: east rock and Dove nests. Four types of shelters were distinguished: (a. adjacent to stipa: grassy small shrub, b. exposed: without shelter, c. under rock which shade the nest, and d. tree dove nest). North east orientation showed the most constant temperature after dove nest. One way ANOVA comparison between the positions was significant P-value < 0.0001, F= 13.3 and df =7, 280.

East position is warmer in the morning but cooler in midday. All ground nest positions showed extremely high temperatures up to 45-60˚C during midday within late May and early June in desert open land habitats. Exposed nest temperatures reached up to 70˚C at that time. On the other hand, house sparrow and dove nests remained with nonlethal temperature about 39˚c

(Figure 5.8-5.9). In June-July, incubated dove nest temperature was 40-45˚C during the middle of the day. On 20th of July 2008, the temperature in a vacant dove nest reached 51˚C, whereas in a south positioned nest temperature reached 76˚C, higher than exposed nest (67˚C). In this case, adjacent plant cover may act negatively at ground nests by holding radiated temperature and blocking air influence.

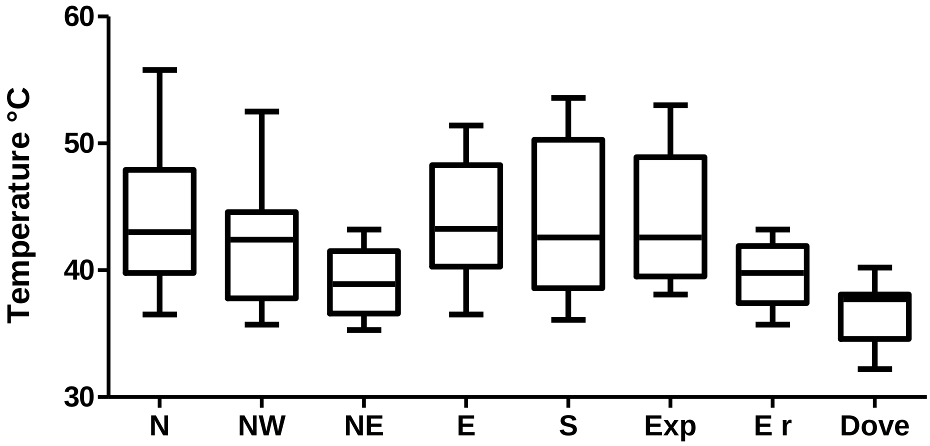


***Figure 5.8** Box plot of shelter and position effect on temperature in pseudo-nests during mid May 2009. Different position of nests N: north, NW: northwest, NE: northeast, S: south, E: east, E r: east rock and Dove nests. Four types of shelters were distinguished: (a. adjacent to stipa: grassy small shrub, b. exposed: without shelter, c. under rock which shades the nest and d. tree dove nest). One way ANOVA comparison among the positions was significant P-value < 0.0001, F= 22.42 and df =7, 280.*

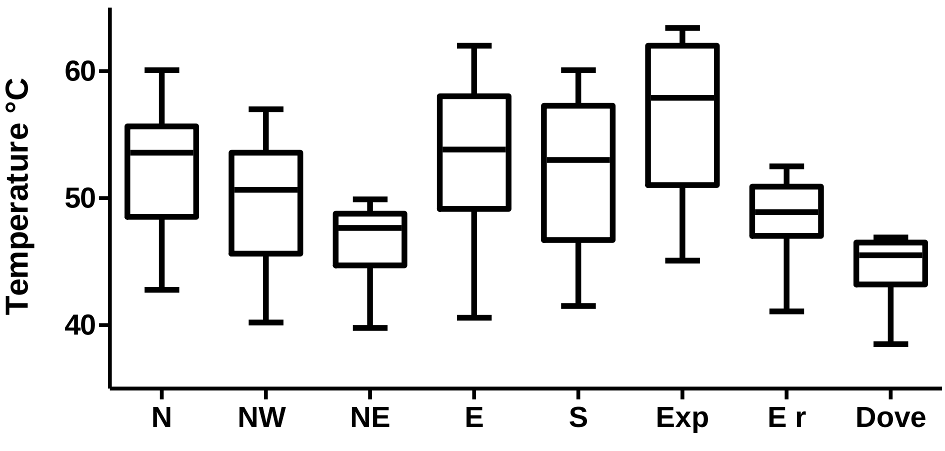


***Figure 5.9** Box plot of shelter and position effect on temperature in pseudo-nests during late May 2009. Different position of nests N: north, NW: northwest, NE: northeast, S: south, E: east, E r: east rock and Dove nests. Four types of shelters were distinguished: (a. adjacent to stipa: grassy small shrub, b. exposed: without shelter, c. under rock which shades the nest and d. tree dove nest). One way ANOVA comparison among the positions was significant P-value < 0.0001, F= 31.37 and df =7, 280.*

The Pivot farm temperatures were 10-15˚C lower than SAANR (semi-arid desert PA) in the middle of the day (Figure 5.10). Temperature of exposed nests, shaded (by desert vegetation) nest and dove nest were 53-68˚C, 45-50˚C, 43-46˚C in SAANR respectively and 48-61˚C, 38-45˚C, 36-40˚C in the Pivot farm respectively during the middle of the day.

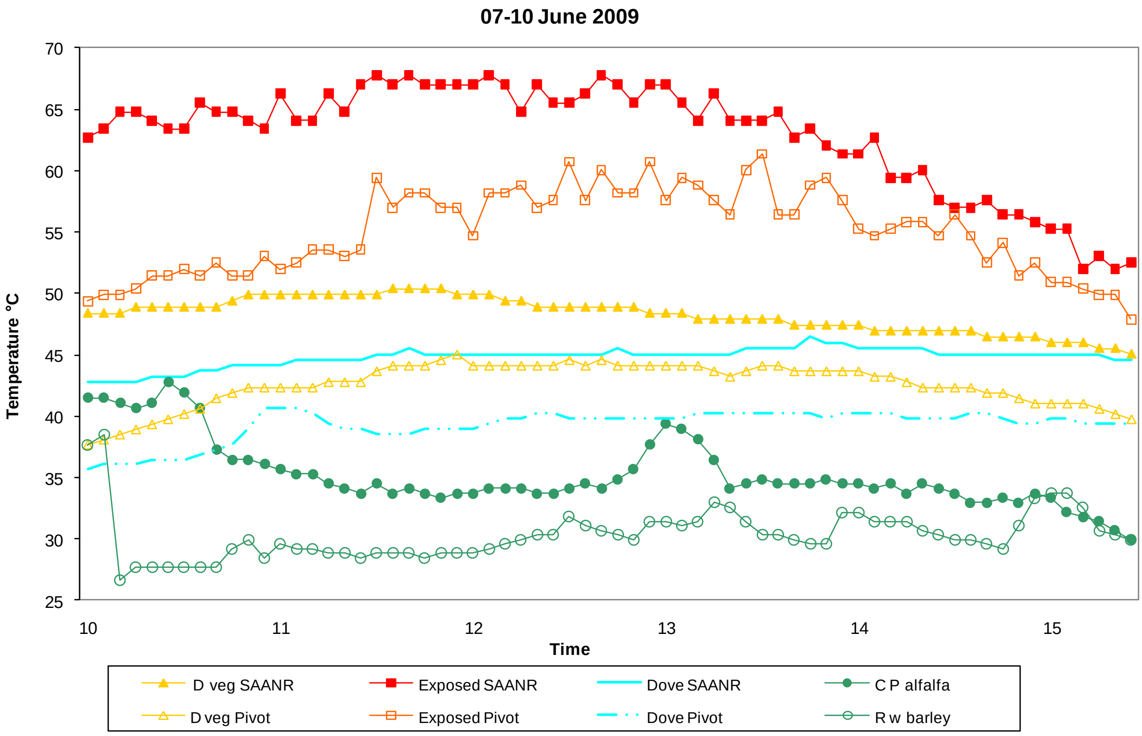


***Figure 5.10** A comparison of temperature in wet and dry habitats during 7-10 June 2009. The wet habitat was the Pivot farm while the dry habitat was Sabah Al-Ahmed Natural Reserve (SAANR). Three types of nests were compared in two areas: the Pivot and SAANR and two different nest habitats were compared in the Pivot. Eight nests types were: desert vegetation SAANR nest (D veg SAANR), desert vegetation Pivot nest (D veg Pivot), exposed SAANR nest (Exposed SAANR), exposed Pivot nest (Exposed Pivot), dove SAANR nest (dove SAANR), dove Pivot nest (dove Pivot), central Pivot trefoil nests in the Pivot (Central P trefoil) and real wet barley nests in the Pivot (R wet barley nest). All paired t-test for comparable nests (D veg, Exposed and Dove) of the Pivot and SAANR and for (alfalfa and barley) were significant P<0.0001, df=65.*

Real incubated crested lark nests (n=4) were found with temperature fluctuating between 25-27˚C in May, due to irrigation intervals and dense alfalfa 60cm (Figure 5.11). In addition, there was a difference between central and border nests within alfalfa crops, especially at midday hours 11am-2pm (Figure 5.12 and 5.13).

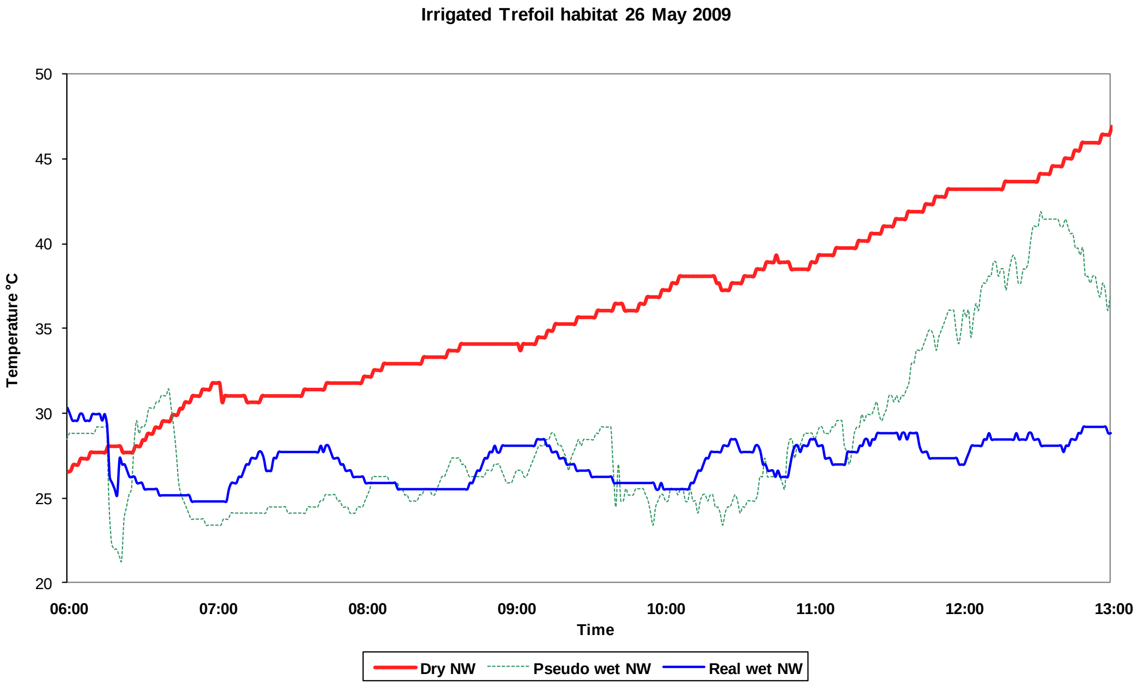


Figure 5.11 A comparison of shelter and position effect on temperature in pseudo-nests during late May 2009. Different position of nests: dry north west (Dry NW), pseudo wet north west (Pseudo wet NW) and real wet north west (Real wet NW). Both pseudo nests were remarkably influenced by ambient temperature to exceed 40°C. While the temperature of pseudo wet north west nests fluctuated up and down, the temperature of real wet north west nests were more stable.

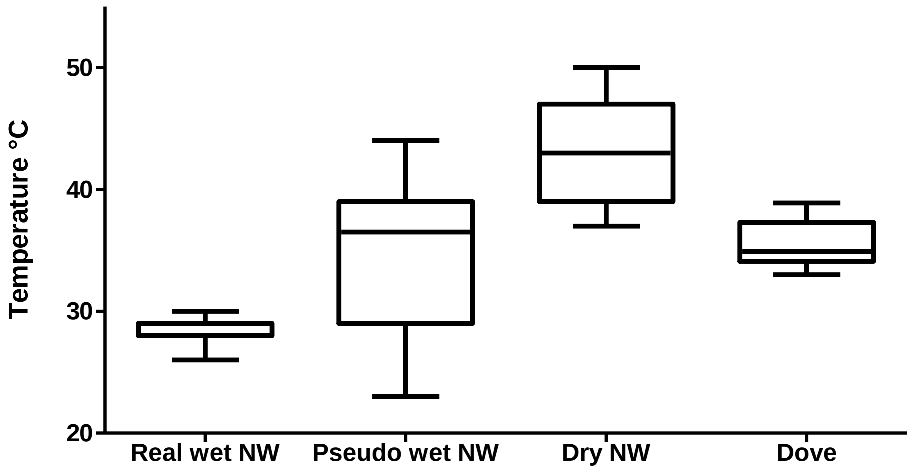


Figure 5.12 Box plot of shelter and microhabitat effect on temperature in pseudo and real nests during late May 2009. Different nests: north west (NW). Four types of nest habitats were used. The real wet north west showed the most constant temperature followed by the dove nest. One way ANOVA comparison between the positions was significant P-value < 0.0001, F= 683.7 and df =3, 1012.

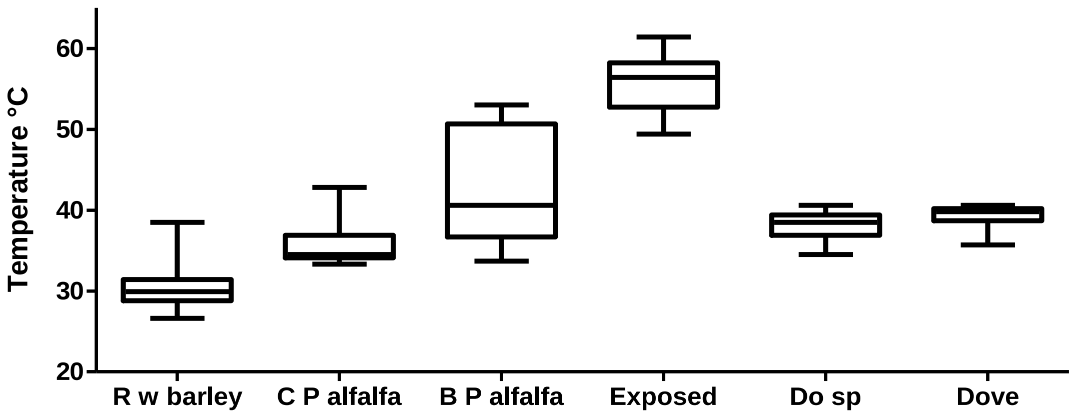


Figure 5.13 Box plot of shelter and microhabitat effect on temperature in pseudo and real nests during early June 2009. Different nests: real wet (R w), central pseudo (C P), boarder pseudo (B P) and house sparrow (Do sp). Six types of nest habitats were used. One way ANOVA comparison among the positions was significant P-value < 0.0001, F= 248.6 and df =5, 282.

In the mid and late June 2009, the temperature increased in all nest habitats (Figure 5.14). It exceeded 40°C in most habitats even in dove nest. Dry habitats became unsuitable for ground nesters where temperature rose above 45°C and 60°C in shaded and exposed nests respectively. Wet habitats were the alternative choice for ground nesters such as crested larks. But there was a significant difference between the temperature of alfalfa and barley habitats. In alfalfa habitats the temperature of crested lark nests fluctuated between 35°C to 41°C. On the other hand, barley habitats were characterized by constant temperature 27°C in midday time while the temperature of exposed nests reached very extremely lethal values. However, temperature of real dove nests was slightly above 40°C during the whole period of the middle of the day. At that time of abnormal temperature reached to 43°C those dove were found incubating their eggs. Presence of chicks later on in those incubated nests was a sign of that this dove nest was successful.

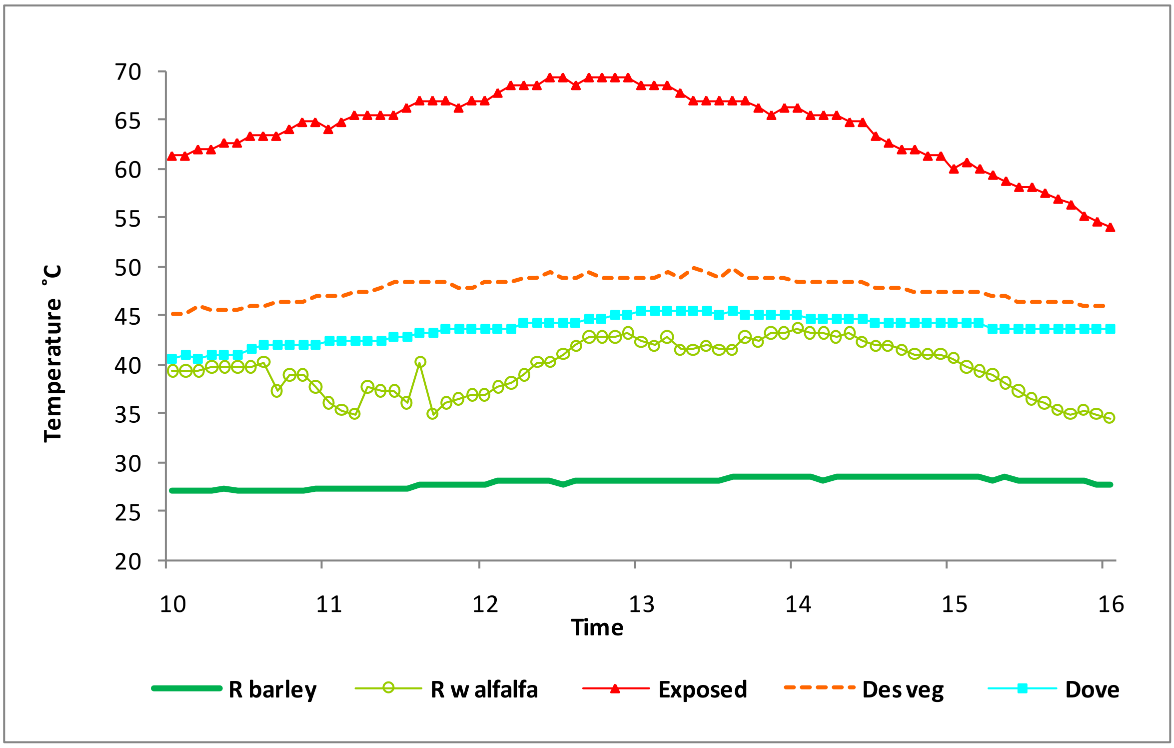


Figure 5.14 A comparison of shelter and microhabitat on temperature effect in pseudo and real nests during mid to late June 2009. Different nests: real barley nest (R barley), real wet alfalfa nest (R w alfalfa), pseudo exposed nest (Exposed), pseudo desert vegetation nest (Des veg) and real dove nest (Dove). Five types of nest habitats were used. The real barley nests showed the best constant temperature followed by dove nest.

5.2.4 Discussion:

Palm doves, collared doves and house sparrows did not show a specific nest position. Bar-tailed lark, black-crown sparrow lark and crested lark may prefer an easterly position in the early breeding season and northeast or northwest later on to cool their nest by prevalent winds. On the other hand, greater hoopoe lark seems to be able to incubate eggs while directly facing the sun. In Saudi Arabia in 2008-09 I saw four nests of greater hoopoe larks all in positions fully exposed to the sun.

There seems some correlation between nests and plant species. The preferred native plant species for nesting were *Haloxylon salicornicum*, *Stipagrostis* *plumosa*, *Rhanterium epapposum* and *Salsola imbricata*. In arable land, alfalfa, barley and pumpkin were used as shelters for lark nests. However, shelter plants may vary according to available vegetation cover which can offer stable and suitable shade.

Temperature difference between ground and tree nests explains why lark breeding ceases in semi-arid areas during summer, while house sparrow and doves continue to breed. The Pivot farm presents a good alternative habitat for crested larks to breed until mid-June.

A female will need less maternal effort if she nests in barley crops instead of alfalfa crops. Non-incubated alfalfa nests showed a limited increase in temperature 37-42˚c (1 hour) in early midday and 35-40˚c (1/2 hour) in late midday, due to crop texture interspaces in early June. On the other hand, barley nest temperature remained almost constant 27-33˚c in 7-10 June.

Barley texture blocks sunrays totally, as the crop grows. Humidity and dense crops in arable areas play an important role in nest thermoregulation. The microclimate of nests within tall and dense barley crops in mid June was similar to irrigated early May alfalfa crops, and probably to January or February semi-arid area nests.

As barley grows it becomes better than alfalfa crops in providing nest shading. It keeps the microclimate temperature constant around 25˚c in late June when exposed nest temperature can reach 75˚C. But, this microclimate may demand a continuous incubation to provide necessary temperature for embryonic development.

By late May, temperature of all nest positions within semi arid habitats rose above 40° C most of the day time. Since 9:30-10:00 morning temperature in all nests exceeded 40°C until 17:00. Position of nests has a limited capacity to minimize or control the temperature of nests by facing leeward. Extremely high temperature of a nest 50˚C up to 60-65˚C makes incubation lethal and impossible during June in arid environment desert.

This study explains why nests of crested larks were covered totally or mostly by a plant shelter. Crested larks tend to nest under plants instead of nesting adjacent to plants cover in order to get sufficient shade.

Chapter 6: The Thermal Challenge 2: Eggshell Adaptation

(A Comparison of Avian Eggshells in temperate and arid zones)

Abstract

The avian egg shell provides an important interface between the developing embryo and the local environment, and its structure is likely to vary in relation to environmental variables. In this chapter I compare components of egg shell structure in Kuwait birds with related samples from elsewhere. A comparison of components of egg shell morphology reveals the presence of morphological and structural differences both between sibling species, and within the same species, collected at different latitudes. Two sibling species, crested larks *Galerida cristata* (from Kuwait) and skylarks *Alauda arvensis* (from the United Kingdom) have almost same body size, different egg volume, shell pigmentation and colour, thickness and water loss through the shell. Skylarks have a larger egg volume than crested larks. While both species have brown eggshells, the eggshells of skylarks have darker pigment colours (background and speckles) than crested larks. Skylarks have thicker eggshells than crested larks, and water loss through crested lark eggshells was eight times higher than through skylark eggshells. The other sibling species comparison that I carried out, involving three species of doves, showed that laughing doves *Streptopelia senegalensis* (from Kuwait) and collared doves *Streptopelia decaocto* (from South Africa) have thinner eggshells and smaller egg volume than cumulet pigeons *Columba livia domestica* (Euopean, collected in UK). But, they did not show a significant difference in their water loss when egg size was taken into account. However, Kuwait laughing doves have thicker eggshells and larger egg volume compared with the South Africa laughing doves. Within the same species, the house sparrow *Passer domesticus,* variation in eggshell thickness was also found between birds from Kuwait and the United Kingdom. The eggshells of house sparrows were thinner in Kuwaiti samples than in those collected in the United Kingdom. Moreover, within the United Kingdom there was also a similar latitudinal trend, with Scottish shell samples being thicker and those from further south in the UK being thinner. There was however little difference in water loss.

These results suggest some local adaptation in egg shell structure, which might be due to phenotypic plasticity or genetic variation. Egg shell thickness increased at higher latitudes in both the sibling species, and in the within species, comparisons. This suggests that latitude, presumably via the effects of environmental temperature, can influence eggshell structure, since the pattern was similar across the lark species compared with the within species variation in the sparrows. Since water loss is higher in thinner shells, and reducing water loss at low latitudes is expected to be important, this result seems somewhat paradoxical. Further studies on the eggshell structure (such as pore active area, canal types and pore density) within these species are needed to understand the adaptive significance of having thicker egg shells at higher latitudes. Differences in canal types and pore density may explain why house sparrows show differences in shell thickness but not much difference in water loss. Location of the nest site and nest structure is also likely to be very important, and this, and other possible contributory factors, are discussed.

Keyword: skylark, crested lark, house sparrow, doves, egg volume, eggshell thickness, water loss, pigment, latitude.

6.1 Introduction

In comparison to the viviparous mammals, avian embryos are more susceptible to inhospitable or extreme environmental circumstances (Carey 1980). Breeding birds have adaptations to enable them to warm or cool their eggs more effectively during the incubation period. Within the larks *Alaudidae*, there is marked variation in nest site location which might be related to the incubation requirements they encounter in different areas. Spring-summer breeding in low latitude regions, where the temperature is high, requires high effort from parents during the incubation period. Reproduction and survival in high temperature environments may be constrained by the amount of time, water and energy that parents can allocate to rearing offspring. Both behavioural and structural adaptations can occur, including appropriate nest site selection and timing of breeding. Nonetheless, demands on the parents are likely to be high. For example, greater hoopoe larks *Alaemon alaudipes desfontaines* in Saudi Arabia were found shading their chicks about 5 hours per day to protect them from solar radiation, a considerable demand on their time (Tieleman *et al.* 2003). There are also likely to be adaptations of the eggs themselves. These are likely to include alterations to egg composition and also shell structure.

Across their range, larks show considerable variability in nest orientation and nest cover. For example, the crested lark *Galerida cristata*, which breeds in the warmest months of the year in Hungary, prefers artificial nest boxes provided in the most wind-protected locations on roofs, which helps keep the contents dry and at the same time provides shelter and protection from south and south westerly wind directions (Orban 2004). The horned lark *Eremophila alpestris* in north eastern California prefers a more northerly nest orientation, facing prevailing winds during the day and avoiding them in the evening in order to regulate the nest microclimate (Hartman & Oring 2003). Within short grass prairie areas in north central Colorado, the lark bunting *Calamospiza melanocorys* nests beneath shrubs, on the leeward side, or on clumps of grasses (40% covered at midday). As the lark bunting breeds later in the season than the horned lark, it is exposed to higher ambient temperatures and decreased winds. Male lark buntings assist females with incubation, and their black plumage provides the opportunity for egg radiative cover (With & Webb 1993).

The eggshell plays an important role in isolating the embryo from the external environment (Board & Scott 1980) and permits gas exchange (O_2 and CO_2). It is the main source of calcium for development of high-calcium demand organs such as skeleton, muscles and brain (Karlsson & Lilja 2008). Also, it provides an important source of trace minerals (such as zinc, copper and iron) for the developing embryo (Savage 1968). In the eggshell, zinc, copper and iron have been found to represent 6.9%, 33.7% and 9.3% respectively of the total mineral content of turkey eggs *Meleagris gallopavo* respectively (Richards 1997).

Avian eggshells vary greatly in their colour pigmentation, thickness, porosity and pore density. The colour patterning does seem to have a significant heritable component. For example, a long term study on 815 eggs of a colony of village weavers *Ploceus cucllatus cucullatus* over 14 years showed the wide colour variation in weaver eggs to be determined by Mendelian inheritance (Collias 1993). While it is therefore thought that this variation has adaptive significance, there have been relatively few studies of the functional significance of natural variation in egg shell structure, with most studies which have taken place concentrating on egg shell colouration. This work has demonstrated a significant relationship between calcium availability (in soil and food sources) and both pigment darkness and eggshell thickness, where darkness of pigments increases with reduced soil calcium (Jubb *et al.* 2006). Gosler *et al.* (2005) found the darkest spots of the eggshell were in the thinner areas of the shell. Bakken *et al.* (1978) found that dark brown speckles have high reflectance (up to 90%) in the infrared wavelength. In addition, Gosler *et al*. (2005) suggested that protoporphyrine compensates for calcium deficiency to strengthen the thinner areas of shells (and reduce its porosity / water conductance by blocking pores and/or infrared reflectance). Protoporphyrin ($C_{34}H_{34}O_4N_4$) is synthesized in the shell gland and then secreted on the outmost layer (cuticle) of an eggshell (Baird *et al*. 1975). It is responsible for maculation in eggshells; the presence of protoporphyrin alone gives shades of brown coloration and, when combined with biliverdin or zinc biliverdin, other different pigment colours such olive occur (Kennedy & Vevers 1976). Protoporphyrin may strengthen the shell in its potential function as a solid-state lubricant, and infrared reflectance may alter shell surface temperature with possible consequences for water loss and hence cooling (evaporating water uses energy and therefore may cool the egg) (Gosler *et al*. 2005, Higham & Gosler 2006). However, several factors might influence pigment darkness and spread such as habitat, female age, female health and condition, eggshell ash-mass, egg shape, habitat and altitude (Gosler *et al.* 2005, Martinez-de *et al.* 2007). Hence, an enclosed nest style protects eggs of house sparrow from direct sun light and consequent overheating and water evaporation which open nest species such crested larks face. In addition, nest site location of house sparrows as well as doves up to 3 meters above the ground make the nest less vulnerable to heat radiation from ground than crested larks which nest on ground.

Other studies have examined the role of pigment or speckle colours and its response to the solar radiation. Lahti (2008) considered the pigment colour to be an adaptation to solar radiation; in the sunnier nesting climates a population of the village weaver *Ploceus cucullatus* was found to have more intensely blue-green eggs. On the other hand, Bakken *et al.* (1978) considered pigment colouration as having a primarily cryptive purpose with minimum role for protection from solar radiation. Both of course may be important depending on circumstances.

The conflicting results about the main role of pigment in eggshells are possibly due to different interpretations of data, small sample sizes, examining different species or variation in materials and methods such as using different paint pen-colour to study the effect of pigmented and non-pigmented eggs on solar radiation reflectance (Montevecchi 1976). Shell colouration and patterning has also been related to other factors including defence against brood parasites (Kilner 2006), strengthening the eggshell as mentioned above (Gosler *et al.* 2005), immunity (McPhee *et al.* 1996 and

Nakagami *et al.* 1993), maternal attractiveness (Moreno & Osorno 2003) and diet (Hargitai *et al.* 2010).

Shell structure has been shown in experimental studies to be very sensitive to dietary factors. Balnave and Muheereza (1997) experimentally showed that sodium bicarbonate $NaHCO_3$ in the diet of hens improves the eggshell strength (improved elasticity of the egg shell as measured by deformation) in response to high temperature. Egg weight and eggshell quality improved when ground limestone as a calcium source was increased in their diet (Makled & Charles 1987).

Egg shell structure is of considerable importance to embryo viability. Eggshell thickness, pore density and active porosity area affect respiratory gases and water vapour diffusion. During incubation, gas exchange through the microscopic pores of the shell is associated with water loss (Rahn *et al.* 1977 and Carey 1980). Eggshell permeability needs to balance water loss to avoid dehydration until hatching takes place (Walsberg 1985) especially in hot dry climates. However, gas exchange across the shell is influenced by atmospheric temperature, humidity (Walsberg 1985) and pressure (Carey 1980, Rahn *et al.* 1977). Incubation in hot climates can potentially expose avian embryos to lethal temperatures due to overheating when the parent is off the nest (Carey 1980). For example mourning doves *Zenaida macroura* breed in Sonora Desert during June and July when the air temperature is 43-48 °C (Walsberg & Voss-Roberts 1983). This example is similar to the Kuwait situation where temperature is very high. I found crested larks *Galerida cristata*, collared doves *Streptopelia decaocto*, laughing doves *Streptopelia senegalensis* and house sparrows *Passer domesticus* incubating their clutch when ambient temperature exceeded 50 °C in Kuwait (Chapter 4: Nest temperature) and nest temperature of laughing doves was also found to be extremely high, up to 46 °C (Chapter 4). The parent can shade the eggs during incubation, but when the egg is exposed to such high temperatures for brief periods, as when the incubating bird is off the nest, then water loss could be substantial. It is therefore to be expected that selection will favour changes to shell structure that might prevent excessive water loss during brief periods of exposure to high temperatures. Supporting this, Ar and Rahn (1985) reviewed eggshell water conductance and pore density of 161 species and found some variation between birds nesting in desert nests and those in more humid areas. Sand partridge *Ammoperdix heyi* and black-billed sandgrouse *Pterocles orientalis* as desert nesters have lower pore density and water conductance than the more humid nesting pied-billed grebes *Podilymbus podiceps* and western grebes *Aechmophorus occidentalis* (Ar & Rahn 1985) which nest in water soaked vegetation.

Eggshell thickness is also known to be influenced by additional environmental factors, notably pesticide contamination (Enderson & Wrege 1973). Since 1946, when organochlorine insecticides such as Dichlorodiphenyltrichloroethane (DDT) were used in agriculture as insecticides, a significant reduction of shell thickness occurred in raptors and seabird eggs world wide and particularly during 1950s and 1960s (Steidl *et al.* 1991, Olsen *et al.* 1993, Pyle *et al*. 1999, Pollock 2001, Swarup & Patra 2005, Jagannath *et al*. 2008, Cherry & Gosler 2010). Thinning of eggshells as a result of DDT was seen in nine Australian raptor species (Olsen *et al.* 1993), peregrine falcons *Falco peregrinus* (Clark *et al*. 2009), Spanish imperial eagles *Aquila adalberti* (Hernandez *et al.* 2008), reed cormorants *Microcarbo africanus*, African darters *Anhinga rufa*, cattle egrets *Bubulcus ibis* and African sacred ibises *Threskiornis aethiopicus* (Bouwman *et al*. 2008). Enderson and Wrege (1973) studied eggs of the prairie falcon *Falco mexicanus* in Colorado in 1967-68 and 1972. They found shell thickness in

1967-68 to be thinner than in 1972 due to higher DDE egg residues in the former than the latter. Many studies have involved eggshells collected from agricultural areas, and chemical or organic compounds within fertilizers may influence eggshell thickness and structure. Awareness of such influences when comparing shells in relation to habitat features with a view to identifying adaptive patterns will avoid researchers drawing misleading conclusions based on impure or contaminated samples.

The purpose of this study was to compare eggshells of desert birds breeding at high ambient temperature and low humidity with birds breeding in temperate and mesic climates. As mentioned above, crested larks *Galerida cristata*, collared doves *Streptopelia decaocto*, laughing doves also named palm doves *Streptopelia senegalensis* and house sparrows *Passer domesticus* were found incubating their clutches when ambient temperature exceeds 50°C in Kuwait. Thus adaptations to water loss are likely to be very important. I compared eggshell water conductance, thickness and functional pore area in these species with closely related temperate species i.e. skylarks *Alauda arvensis*, cumulet pigeons *Columba livia domestica* and with house sparrows breeding in Britain where temperature during incubation is usually less than 20°C.

6.2 Methods

In order to examine the effect of latitude on eggshell features, I compared two sets of related species nesting at different latitudes; larks and doves. Larks were crested lark *Galerida cristata* and skylark *Alauda arvensis*. Doves were cumulet pigeon *Columba livia domestica*, laughing dove *Streptopelia senegalensis* and collared dove *Streptopelia decaocto*. In addition, I compared shells of the same species, the house sparrow *Passer domesticus*, in different latitudes.

Egg Samples

Eggs were obatined from three regions: 1) low latitude hot arid zones in Kuwait (from 28° to 29° north of the equator line), 2) high latitude cold temperate zones in England (from 50° to 52° north of the equator line) and 3) high latitude cold temperate zone Scotland (from 56° to 58° north of the equator line). Kuwaiti egg samples were collected from abandoned or nests destroyed after harvesting and wind storms. Samples from the temperate species collected in England and Scotland were obtained from museum collections (supplied by the Hunterian Museum, Glasgow and from the Natural History Museum Tring, UK via Dr Phillip Cassey, University of Birmingham). Egg samples were also obtained from pigeons breeding in Glasgow (cumulet pigeons *Columba livia domestica*, supplied by Professor Peter Holmes, University of Glasgow).

Where possible, a single egg from each clutch was chosen for the measurements as porosities are likely to be similar in the same clutch (Birchard & Kilgore 1980). In Kuwait, eggs were collected from five species: crested lark *Galerida cristata* n=12 eggs (12 different clutches), house sparrow *Passer domesticus* n=8 eggs (8 different clutches), laughing dove *Streptopelia senegalensis* n=11 (11 different clutches) and collared dove *Streptopelia decaocto* n=3 (3 different clutches).

Samples from temperate zone eggs were from three species breeding in the United Kingdom: skylark *Alauda arvensis* eggs n=4 (4 different clutches), house sparrow *Passer domesticus* n=6 from England (6 different clutches), house sparrow *Passer domesticus* n=6 from Scotland (6 different clutches) and cumulet pigeons *Columba livia domestica* n=16 (8 different clutches).

The following egg measurements were taken; weight (fresh eggs in Kuwait only), length and width. For the Kuwait egg samples and the Glasgow pigeons, eggs were evacuated of their contents, rinsed with water and alcohol, dried and transported to the laboratory for analysis.

Lab analysis

Egg volume: The measurements of length and width of eggs were used to estimate egg volume based on the following formula

$$V = Kv * LB^2 \quad \text{(Barth 1953 and Hoyt 1979)}$$

Where V is volume, L is egg length and B is breadth. I used 0.51 as the volume coefficient Kv which can be used to obtain relatively precise estimates of egg volume for most species of birds (Hoyt 1979).

Digital photo-analysis: Egg samples were kept in opaque dry plastic and carton pockets until photographed digitally in a dark box lined with a black background cloth and supplied with a reference of colour chips from the Jotun company (blue, green, pink, orange and grey) and ruler scale (Figure 6.1). Colour intensity of pigment colours (ground colour and speckle colours) were compared on a computer screen to identify any significant differences between arid and temperate eggs using Image J software. Fifteen small circular spots (0.01mm diameter) on the surface area of each eggshell were tested. The small sample areas (circles) were chosen from the middle surface area of the eggshell with the pointed and blunt poles excluded, since darkness of pigment colours often increases from the pointed pole toward the blunt pole (Polacikova *et al.* 2007). Mean values of colour intensity were used to plot the Red, Green and Blue (RGB) profile of each egg in the 15 different sample areas: a) background, b) light pigments and c) dark pigments (Figure 6.2). RGB value is between (0 and 255), where its value is inversely related to colour intensity. The intensity of colour increases as the value of RGB goes toward zero and decreases as it goes toward 255. Hence, a dark colour (e.g. brown) has lower RGB value than a light colour.

***Figure 6.1** A house sparrow Passer domesticus egg was photographed by digital camera with index colour reference and scaled ruler. All other egg samples were photographed in the same manner.*

Figure 6.2 Intensity of eggshell colour was measured in three circular sample areas: a) Background of eggshell, b) Light pigments and c) Dark pigments. Five circle spots (0.01mm diameter) of each of the three types on the eggshell surface area were tested. Within each area, the samples were taken at random. Mean values of colour intensity were used to plot the Red, Green and Blue (RGB) profile of each egg in different 15 circular spots: a) background, b) light pigments and c) dark pigments.

Conductance G_{H_2O}: Eggshells were sawn longitudinally using a small electric circular saw. Labelled pieces of eggshell were left overnight in an incubator at 34 °C to remove any remnant moisture. The thickness of these shell pieces was measured, including the inner membrane, using a manual micrometer 0-25mm with ±0.01µm accuracy fitted with a curved surface on the inner jaw (Figure 6.3).

Figure 6.3 A manual micrometer 0-25mm with ±0.01µm accuracy fitted with a curve surface on inner jaw

Then, the samples were glued using super glue on the top of 0.5ml labelled eppendorf that was filled with water (Figure 6.4).

Figure 6.4 A fragment or a half of an eggshell sample fixed on the top of eppendorf by super glue.

After one hour, if there was no leakage in the samples (i.e. the eggshell piece was firmly stuck to the top of eppendorff and no water came out when the sample was shaken firmly), I weighed the eppendorf using a digital balance to the nearest 0.0001 mg. and placed the tubes in a vacuum dessicator floored with silica to absorb water vapour.

The dessicator was kept in an incubator at 34°C temperature for 7 days. Each day, I weighed the samples between 17:00-and 18:00 hours to measure the water lost as vapour through the eggshell pores. I also replaced the silica granules in the dessicator with dry ones every day. This was repeated for another 7 days at 40°C to examine the effect of normal and extreme incubation temperatures on water conductance through the shells of the different species.

Change in the mass of the tube plus shell between first and subsequent days is due to water loss through the shell fragment. Conductance (G) can be calculated by the following formula:

$$\boldsymbol{G} = x * 24 / 39.9 * K$$

Where x is the hourly water loss in mg and ***G*** is the conductance in mg / (day· torr · cm^2). Water vapour pressure inside the tube is 39.9 torr at 34 °C, and 0 torr outside in the desiccator (all water removed by silica granules, so the pressure gradient is 39.9). K is a correction for the exposed surface area of the shell fragment; this is 45.80mm^2 for a 0.5ml eppendorf. Hence, if the mass loss per hour is x mg, then:

$$\boldsymbol{G} = x * 24 / 39.9 * 0.4580$$ (Nager, pers. commun.)

Water vapour conductance depends on the number and size of pores. Hence, the more and/or larger the pores are the more water will go through. Conductance also varies inversely with the length of the pore, the longer the pore canal the less water passes through. The length of the pore canal is the shell thickness L.

Here in this measurement, number and size of pores are combined in a value that is generally refered to as a ‘functional pore area’ Ap. Hence:

$$\boldsymbol{G} = Ap / L$$ (Ar and Rahn 1985; Nager, pers. commun.)

Since G and L are measured, Ap can be calculated from the above relationship as:

$$Ap = \boldsymbol{G}\, L$$

6.3 Results

The results show differences in shell structure between eggshells of sibling species and between the same species at the different latitudes. It should be borne in mind that the crested lark sample is small, but so far as I know, not atypical (pers. obs.)

Sibling species:

1. ***Larks:***

Females of the sibling crested lark and skylark species have similar weight, with the former being only slightly heavier (39-47g) than the latter (35-45g) (Cramp & Perrins 1994, Shkedy & Safriel 1991, Dougall 1999, Yom-Tov 2001). Skylarks were found to have a slightly, but significantly larger egg volume than crested larks, albeit based on a small sample of the latter. Mean values of skylark and crested lark egg volumes were 3.53±0.07cm^3 and 3.10±0.09cm^3 respectively (Figure 6.5). According to the limited published papers available, the egg volume of skylarks is about 3.91cm^3 (23 x 17mm) in the United Kingdom (Snow & Perrins 1998, Harrison 1975) and 3.25cm^3 (22.9 x 16.6mm) in Spain (Suárez *et al.* 2005). These published egg volumes of skylarks are therefore also larger than my results were for crested lark egg volume 3.10 ±0.09cm^3, (length 22.56 ±0.041 x 16.37 ±0.19mm) in Kuwait. However, the magnitude of the difference, albeit significant, is quite small.

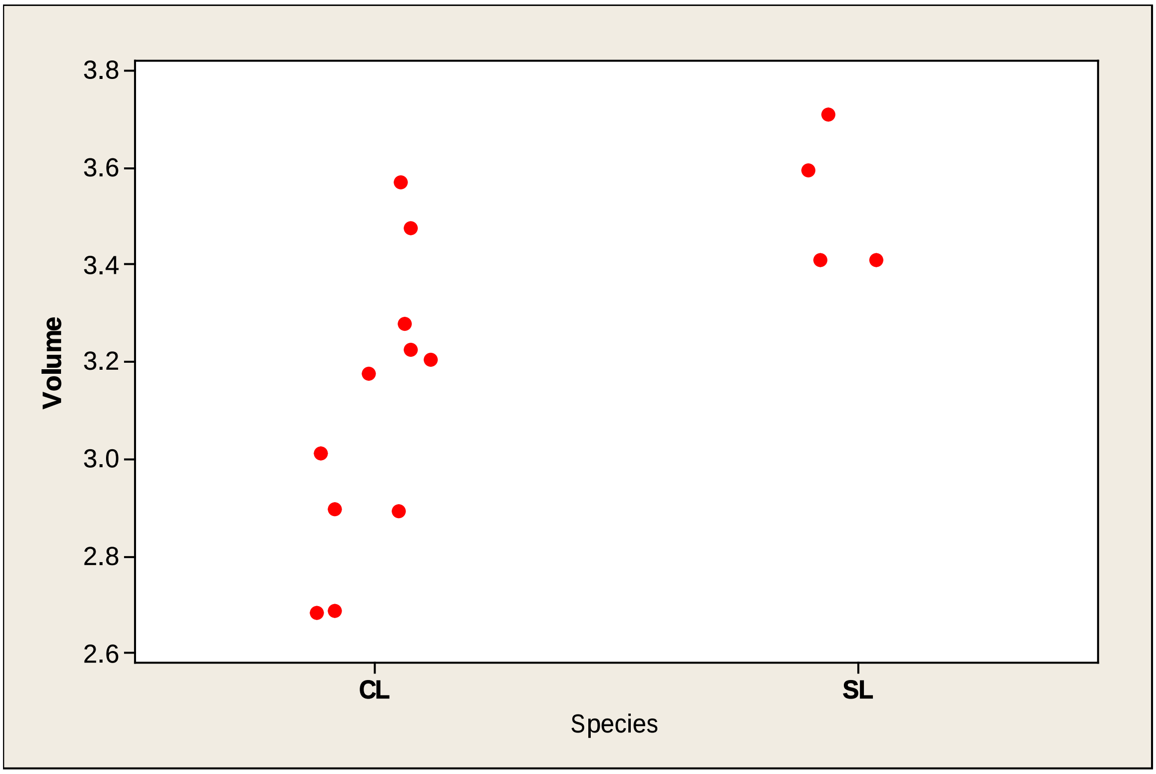


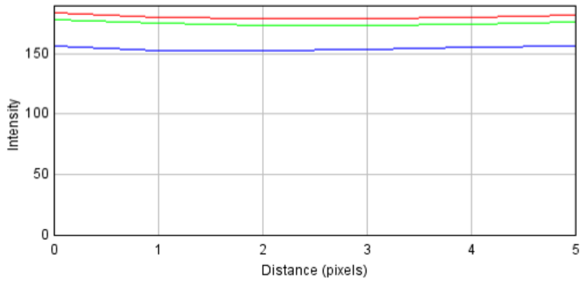
Figure 6.5 A scatter plot showing values of crested lark and skylark egg volumes. Skylark (SL) eggs from United Kingdom and crested lark (CL) eggs from Kuwait. One-way ANOVA: Volume in relation to species P-value= 0.016, F= 7.63 and degrees of freedom= 1, 13.

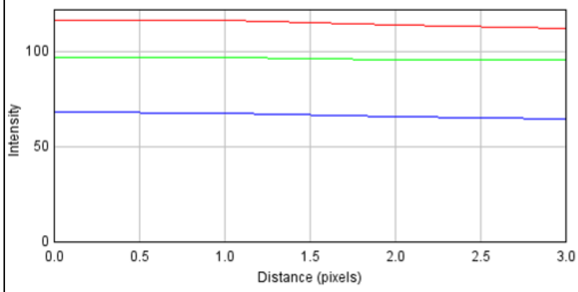
Crested larks from Kuwait State and skylarks from the United Kingdom differed in the pigment colour, thickness and water loss of their eggshells. Eggshell colours of skylarks were darker and had denser pigments than crested larks (Figure 6.6).

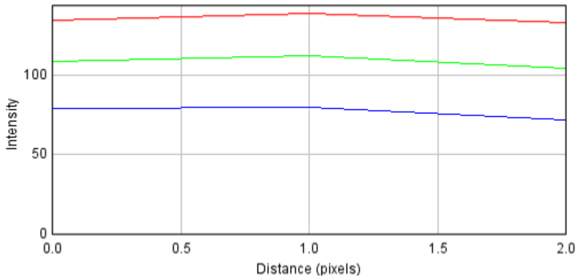
***Figure 6.6** Patterns of crested lark and skylark eggshells. Skylark eggshells from United Kingdom on the left hand and crested larks from Kuwait on the right hand. Skylarks have dark brown pigmented eggshells while crested larks have light brown pigmented eggshells.*

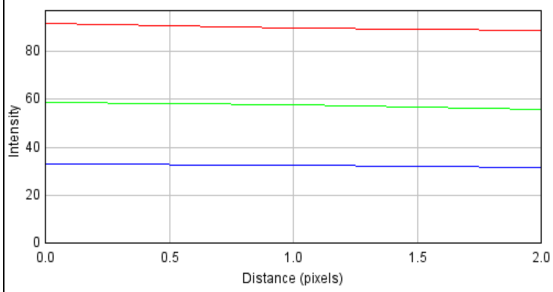
A digital comparison between ground colour and colour pigments of crested lark and skylark eggshells was done by using Image-J software. I measured RGB profile of pigments and speckles of crested lark and skylark eggshells (Figure 6.7).

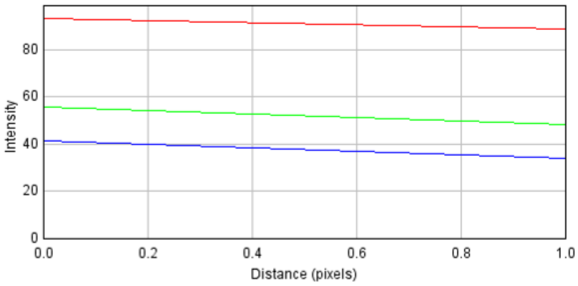
Intensity of colour is expressed here by RGB values. Values range from not to 255 (in arbitrary units). High RGB value means high intensity of colour. In comparison to crested larks, skylark eggshells have pigment colours with low values of RGB in the ground colour, light pigments and dark pigments. Average RGB values of skylark eggshells and crested lark eggshells were respectively for each colour: (114, 99, 72 – skylark), (172, 169, 148 crested lark) in background, (85, 60, 35), (142, 113, 82) in light pigments and (67, 33, 19), (120, 84, 55) in dark pigments respectively (Figures 6.8- 6.10).

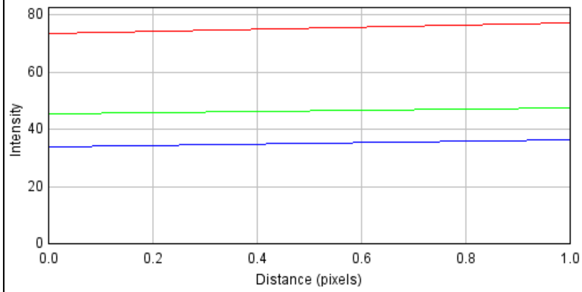
<table>
<tr><th>RGB Profiles</th><th>Crested lark eggshell</th><th>Skylark eggshell</th></tr>
<tr><td>Ground</td><td>

Amber yellowish grey
RGB (172, 169, 148), (Hex) ACA994</td><td>

Dark grayish brown amber
RGB (114, 99, 72), (Hex) 726348</td></tr>
<tr><td>Light speckles</td><td>

Grayish brown
RGB (142, 113, 82), (Hex) 8E7152</td><td>

Brown
RGB (85, 60, 35), (Hex) 553C23</td></tr>
<tr><td>Dark speckles</td><td>

Brown
RGB (120, 84, 55), (Hex) 785437</td><td>

Brown red
RGB (67, 33, 19), (Hex) 432113</td></tr>
</table>

***Figure 6.7** Contrast of average mean RGB profile of ground colour and spot pigments of crested lark and skylark eggshells. Value of RGB measured between (0 and 255), where darkness of colour increase as it value decrease. As a value of RGB goes toward zero it becomes darker. In addition, the nearest representative colour of the eggshell was described by Hexdecimal code (Hex).*

Ground colour of skylark eggshell was "Dark greyish brown amber" compared with "Amber yellowish grey" in crested lark eggshells. There was a significant difference between their ground intensity colours. Ground intensity colour RGB of crested larks was about double the brightness of that in the skylark samples (Figure 6.8). Secondly, light pigments were "Brown" in skylark eggshells compared with "Grey brown" in crested lark eggshells. Statistical analysis revealed a significant difference between light pigments of those two sibling lark species (Figure 6.9). Thirdly, dark pigments were "Brown red" in skylark eggshells compared with "Brown" in crested lark eggshells. Dark pigments in skylarks were twice as dark as crested larks' eggshells (Figure 6.10).

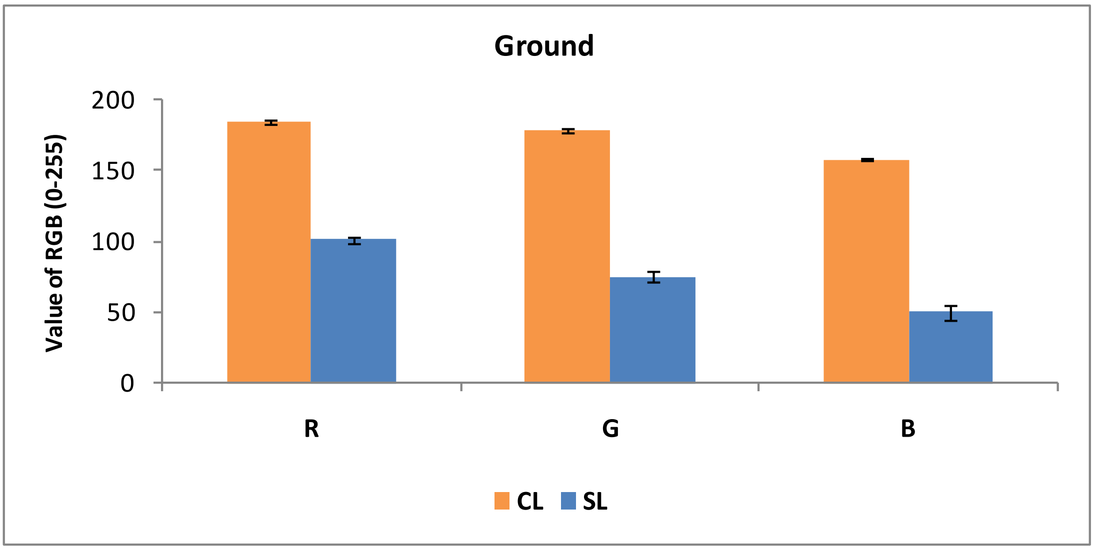


Figure 6.8 Contrast of RGB values of background between crested lark (CL) and skylark (SL) eggshells. Sample size of eggshells (n= 15), CL (n=11) and SL (n=4). One way ANOVA analysis comparing the species P is <0.0001 (for R), <0.001 (for G) and <0.004 (for B). Degrees of freedom=1, 13, for all comparisons, F= 27.157 (for R), 13.045 (for G) and 5.890 (for B).

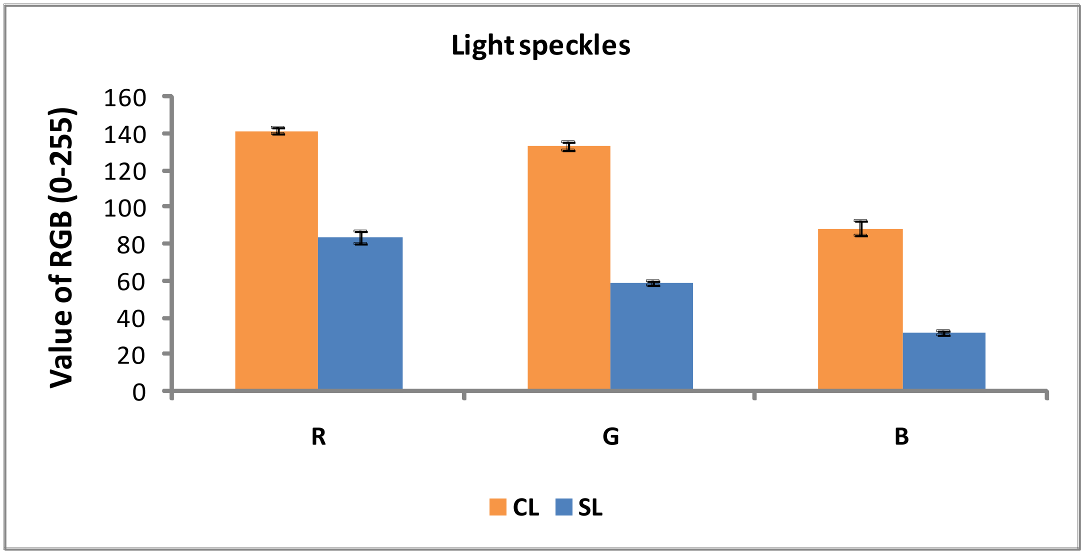


Figure 6.9 Contrast of RGB values of light speckles between crested lark (CL) and skylark (SL) eggshells. Sample size of eggshells (n= 15), CL (n=11) and SL(n=4). One way ANOVA analysis comparing the species P is <0.000 (for R), <0.000 (for G) and <0.000 (for B). Degrees of freedom for all comparisons =1, 13, F= 126.487 (for R), 254.963 (for G) and 465.075 (for B).

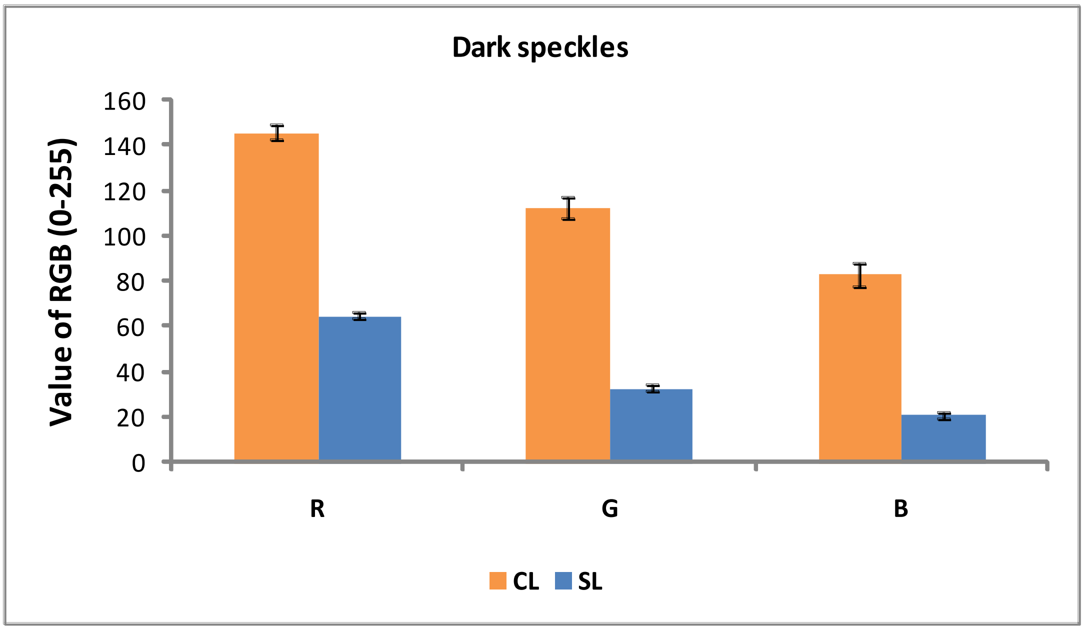


Figure 6.10 Contrast of RGB values of dark speckles between crested lark (CL) and skylark (SL) eggshells. Sample size of eggshells (n= 15), CL (n=11) and SL(n=4). One way ANOVA analysis P is <0.000 (for R), <0.001 (for G) and <0.004 (for B). Degrees of freedom for all comparisons =1, 13, F= 27.157 (for R), 13.045 (for G) and 5.890 (for B).

My results also demonstrated that crested larks have significantly thinner eggshells than skylarks (Figure 6.11).

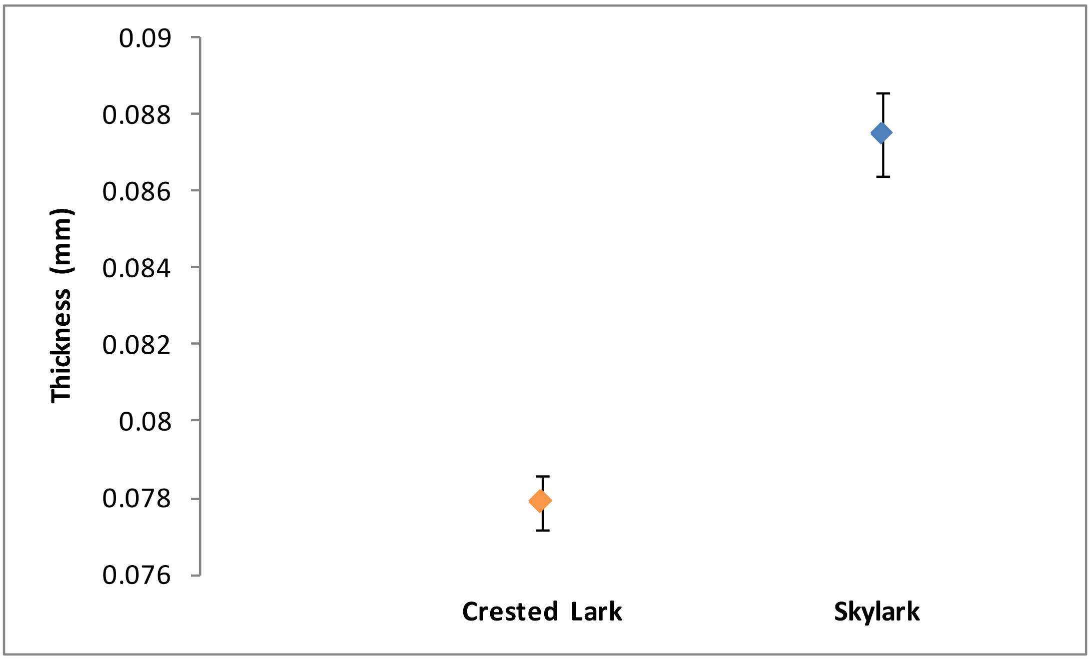


Figure 6.11 Mean value and standard errors of eggshell thickness within two sibling larks. Crested larks (n=11) and skylarks (n=4). Independent sample test (t-test) significant (2-tail): 0.016, degrees of freedom= 13.

I further found a significant difference in water conductance between Kuwaiti crested lark eggshells and United Kingdom skylark eggshells. This was not a consequence of differences in egg volume. , Shell thickness was unrelated to egg volume, and in a general linear model comparing the shell thickness in the two species, with egg volume as a co-variate, was not insignificant. The results showed that inclusion of the covariate did not allow improved estimation of the trend to be obtained, compared with analysis which omitted the covariate.

Water loss from Kuwaiti crested lark eggshells was 8 times more than Scottish skylark eggshells (Figure 6.12). Water loss was not affected by temperature in either species and the species difference was consistent across the two temperatures (Figure 6.12).

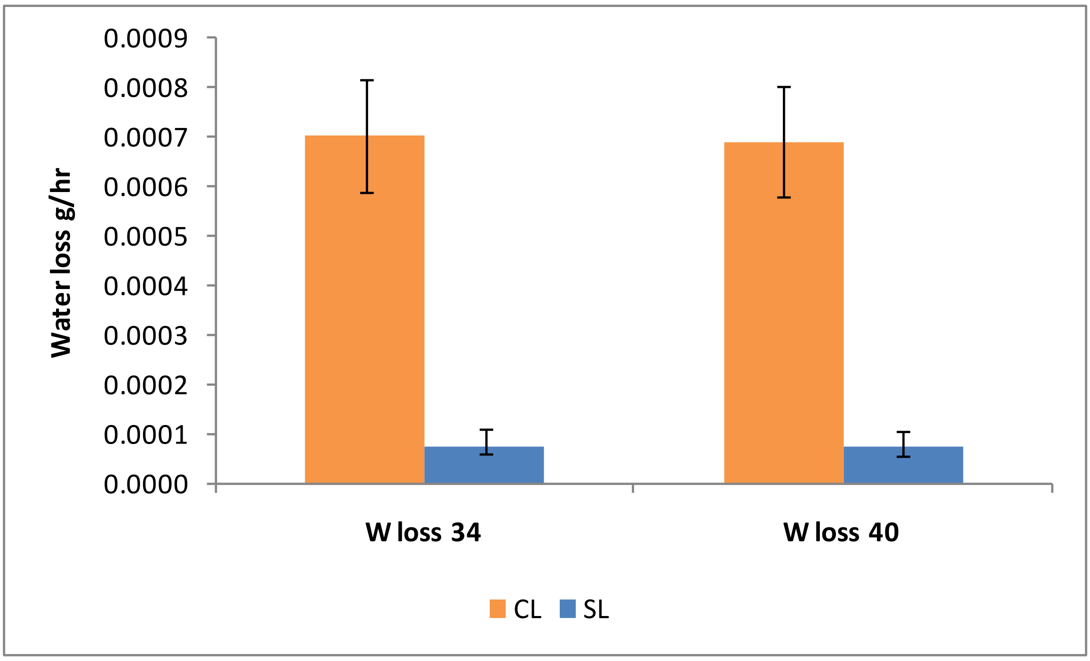


Figure 6.12 Comparison of water loss between eggshells of sibling larks; crested lark (CL) from Kuwait and skylark (SL) from United Kingdom. Variance of water loss per hour through eggshells of crested larks and skylarks were tested at 34°C and 40°C degrees. Sample size was 11: crested lark (n=8), skylark (n=3). Independent sample test (t-test, 2-tailed) was significant for both temperatures 34°C (P = 0.035) and 40°C degrees (P = 0.034). , Variance in temperature did not influence the water loss in either species.

The water loss was not associated with thickness of the larks' eggshells. It does not show a significant decline as eggshell thickness increased and there was no difference between incubation at 34°C and 40°C. Neither crested larks nor skylarks showed a significant relationship between water loss and eggshell thickness (Figure 6.13).

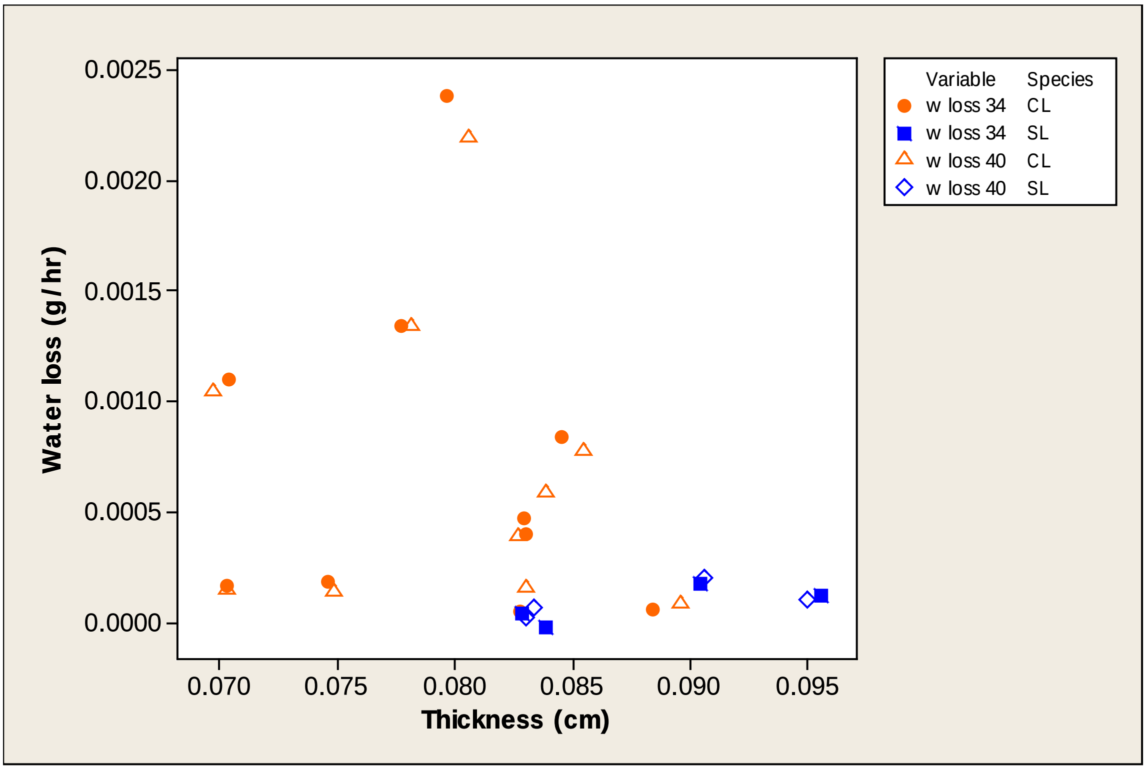


Figure 6.13 Relationships between water loss and thickness of larks' eggshells. In crested larks (CL) n=10, Pearson correlation of water loss and thickness = -0.132 and P-Value = 0.717 at 34°C and = -0121 and P-Value = 0.739 at 40°C. In skylarks (SL) n=4, Pearson correlation of water loss and thickness = 0.572 and P-Value = 0.428 at 34°C and = 0.508 and P-Value = 0.492 at 40°C.

Insignificant relationship between water loss and eggshell thickness in larks most probably means that it is not the length of pores itself which affects the amount of water loss, but the number of pores. Hence, crested larks probably possess more shell pores than skylarks.

Water loss and egg volume did not show a significant relationship (Figure 6.14).

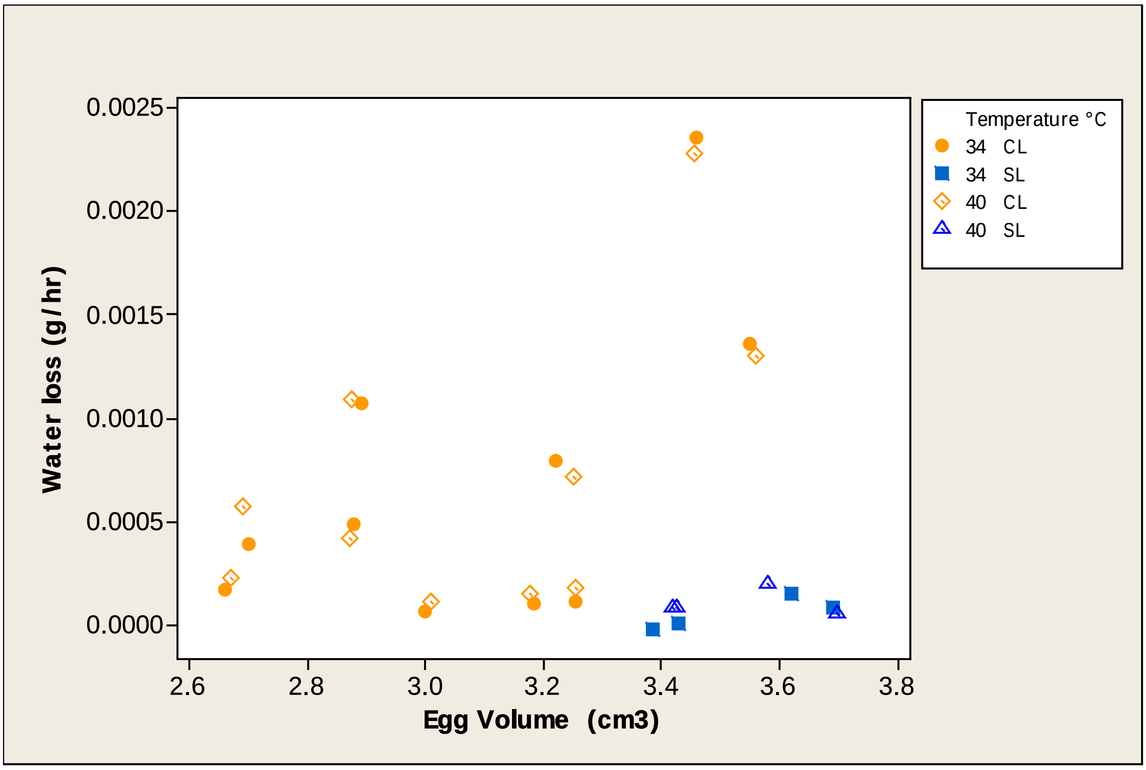


Figure 6.14 Scatter plot of water loss and egg volume of larks. In crested larks (CL) n=10, Pearson correlation of water loss at 34°C and egg volume =0.579 and P-Value = 0.08 and Pearson correlation of water loss at 40°C and egg volume = 0.558 and P-Value = 0.094. In skylarks (SL) n=4, Pearson correlation of water loss at 34°C and egg volume =0.615 and P-Value = 0.385 and Pearson correlation of water loss at 40°C and egg volume = 0.554 and P-Value = 0.446.

Active pore area (calculated as in Methods from water loss and shell thickness) Ap in crested larks was 2 to 3 times higher than in skylarks. The mean active pore area for crested larks and skylarks were 0.00001151 ±0.0000033 and 0.00000187 ±0.00000088 respectively (Figure 6.15).

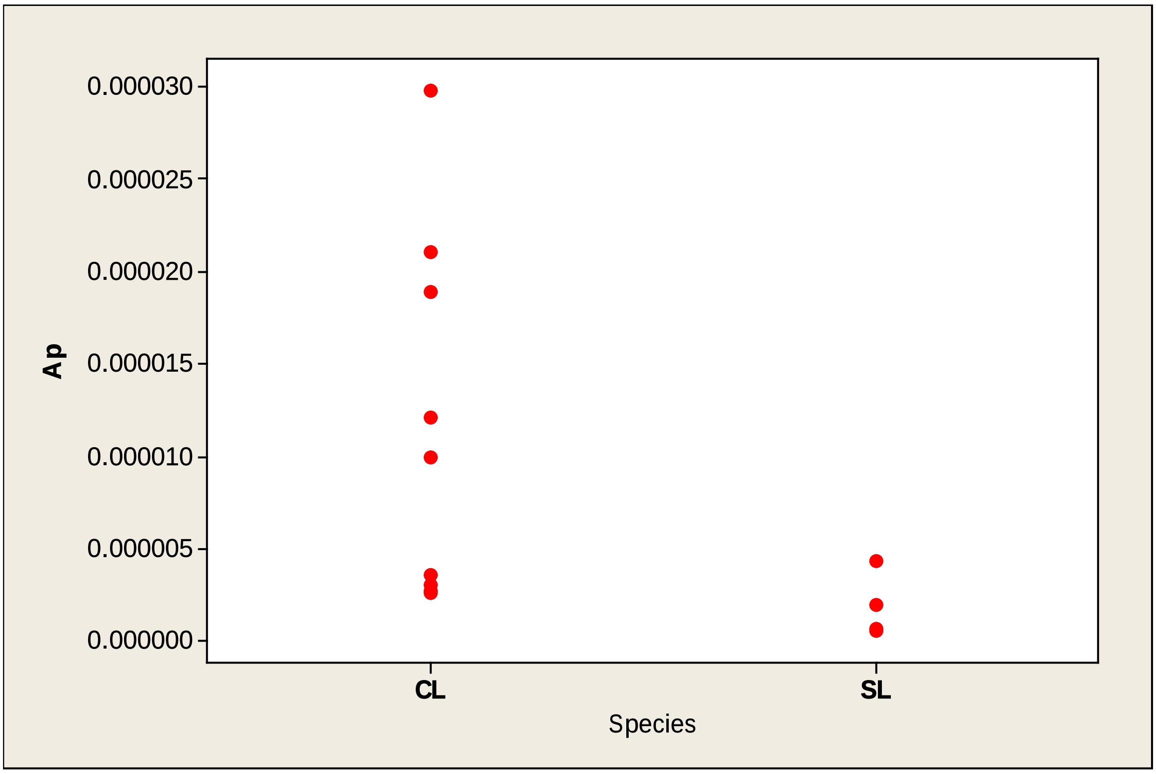


Figure 6.15 Comparison between active pore area (Ap) of crested lark (CL) and skylark (SL) eggshells. Sample size n= 13, CL n=9 and SL n=4. As would be expected given the results on shell thickness and water loss, these are significantly different. Two-sample t-test; T-value= 2.83, P-value= 0.020, df=9.

Egg volume of crested larks alone without skylarks also did not show significant correlation between water loss and egg volume, Pearson correlation of water loss at 34^{o}C and volume= 0.579, P-value= 0.080. Pearson correlation of water loss 40^{o}C and volume= 0.558, P-value= 0.094, though with a larger sample size, the observed tendency for more water loss from larger eggs may be significant in crested larks.

Doves

Eggshell thickness of doves varied between Kuwait laughing dove (LD KW), Kuwait collared dove (CD KW) and cumulet French pigeon (domestic pigeon) in United Kingdom (Figure 6.16 and 6.17). The cumulet pigeons had thicker shells, followed by the collared dove, with the laughing dove having the thinnest shell.

My result about eggshell thickness of collared doves (0.136 ±.002 mm) and laughing doves (0.118 ± 0.004 mm) is consistent with Ar and Rahn (1985). They found collared doves and laughing doves have 130 mm and 120 mm eggshell thickness respectively.

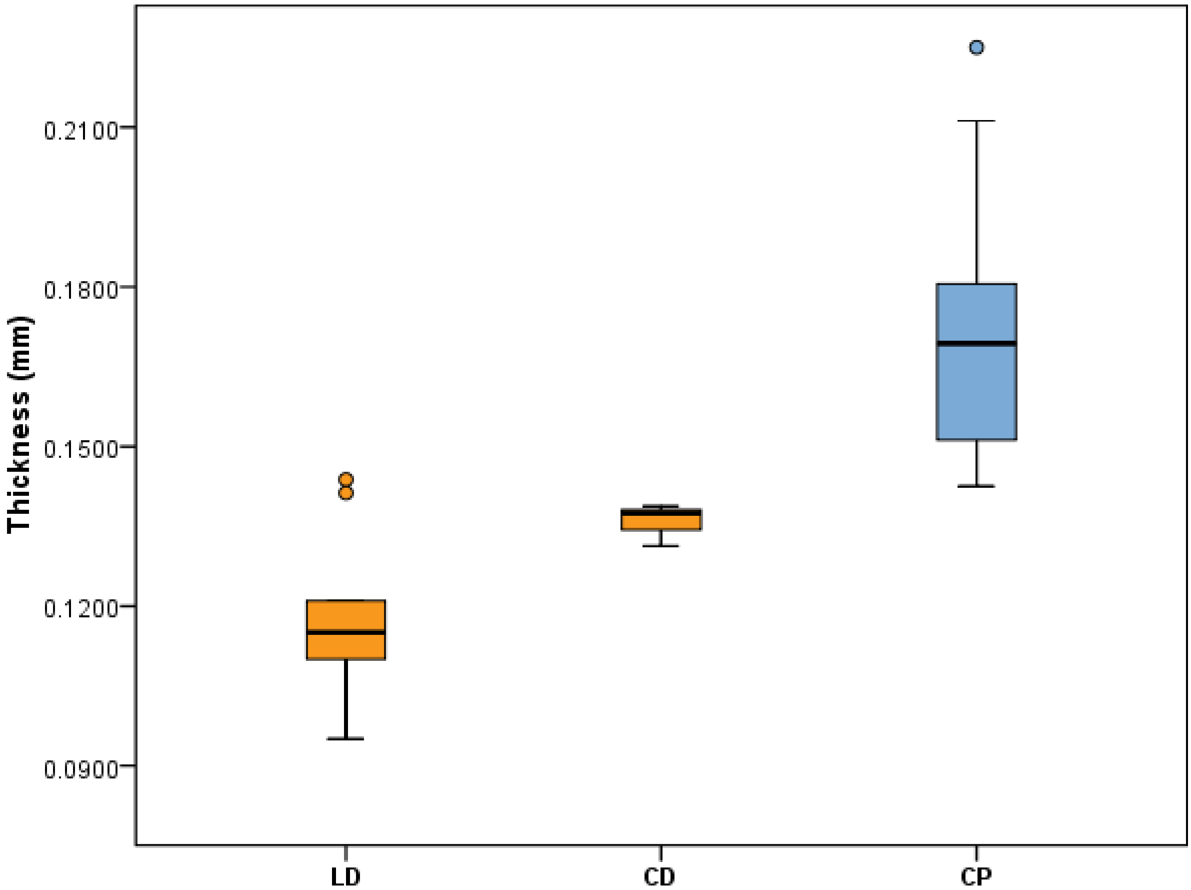


Figure 6.16 A comparison of eggshell thickness between the different doves. Laughing dove (LD), collared dove (CD) and cumulet pigeon (CP) . Sample size (n=30): LD (n=11), CD (n=3) and CP (n=16). One way ANOVA; degrees of freedom= 2, 27, F= 28.91, P-Value= 0.0001

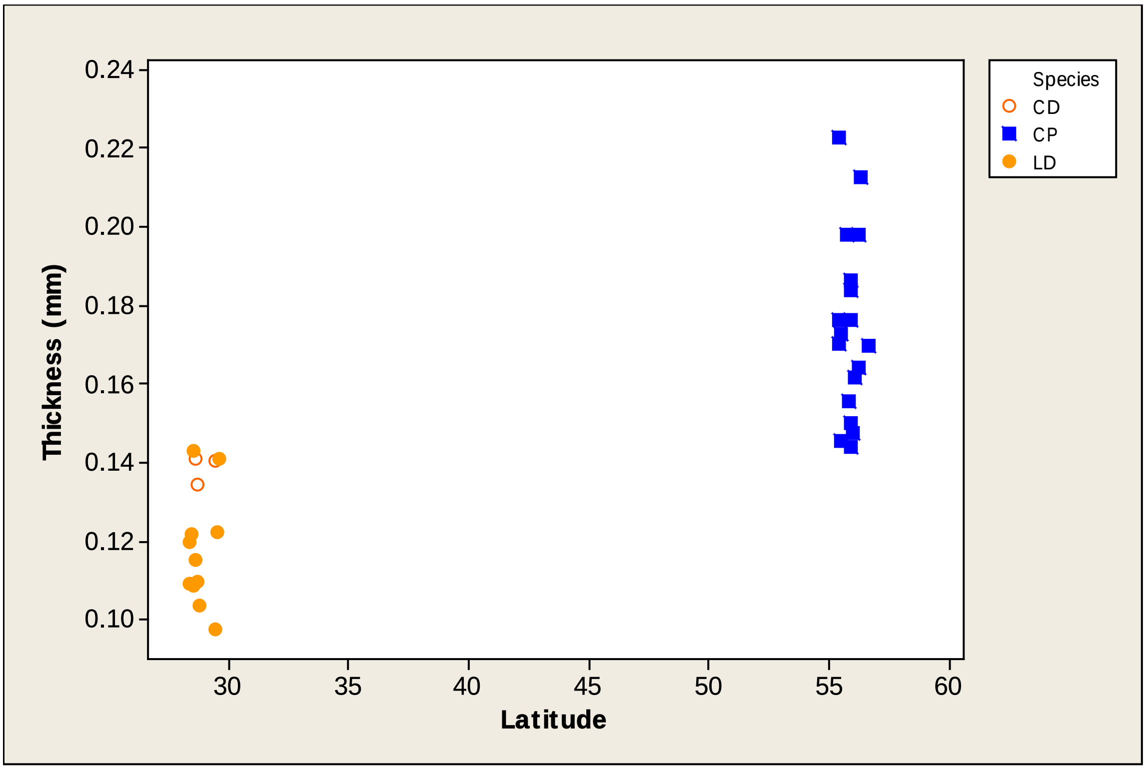


Figure 6.17 Scatter plot of doves eggshell thickness and latitude. Sample size of doves (n=32): laughing dove (LD) (n=11), collared dove (n=3) and cumulet pigeon (n=18)

Water loss did not show a significant difference between laughing dove, collared dove and cumulet pigeon during incubation at 34°C (Figure 6.18) or at 40°C (Figure 6.19). Excluding the small samples of collared doves, there was a significant difference between water loss of laughing dove and cumulet pigeon eggshells (Figure 6.19).

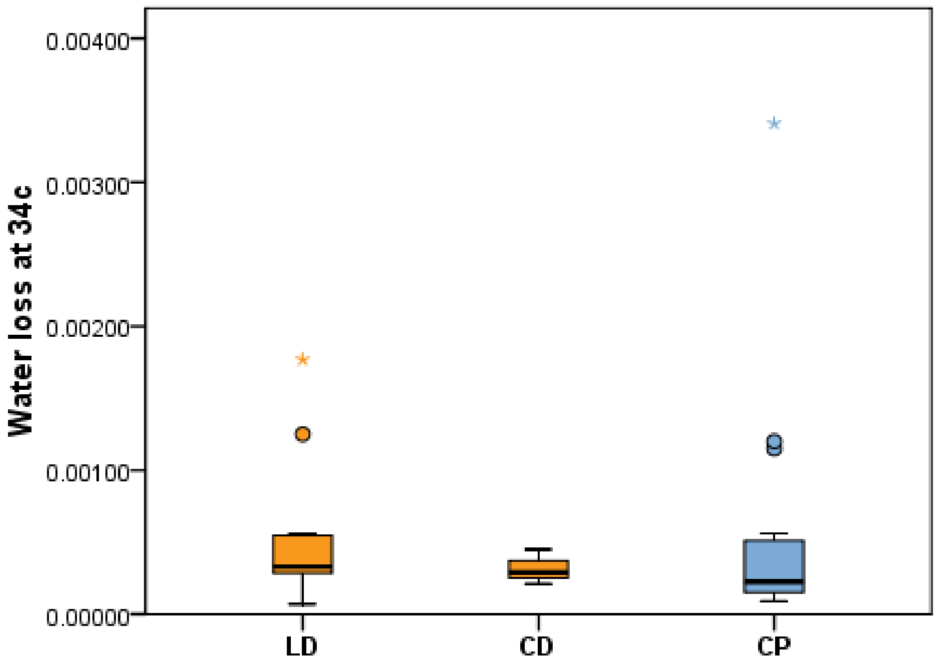


Figure 6.18 A comparison of water loss between the different doves at 34°C . Laughing dove (LD), collared dove (CD) and cumulet pigeon (CP). Sample size (n=31): LD (n=11), CD (n=3) and CP (n=17). One way ANOVA; degrees of freedom= 2, 28, F= 0.13, P-Value= 0.881.

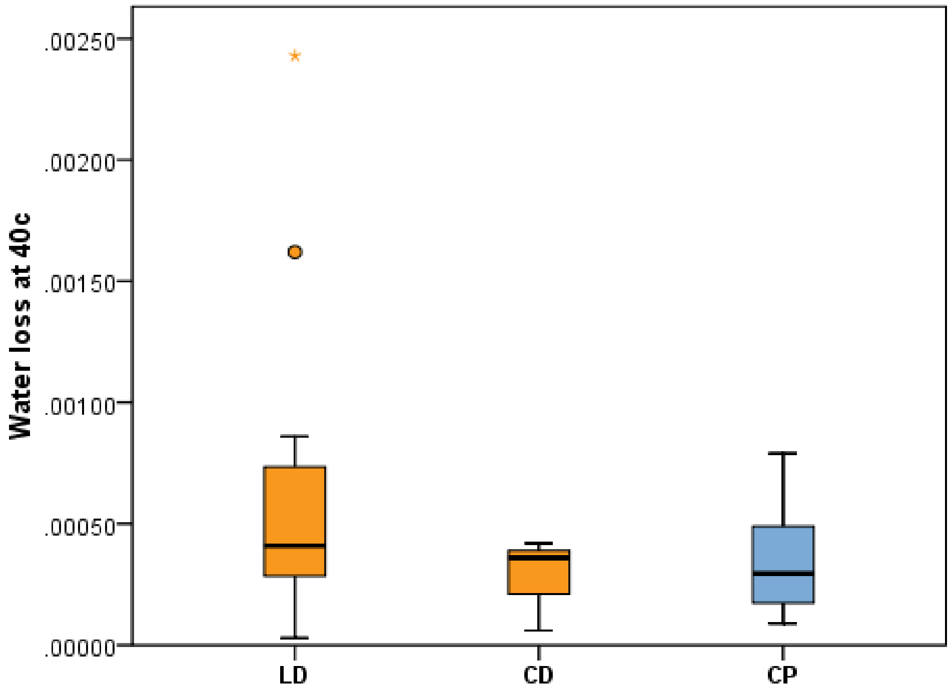


Figure 6.19 A comparison of water loss between the different doves at 40°C. Laughing dove (LD) collared dove (CD) and cumulet pigeon (CP). Sample size (n=31): LD (n=11), CD (n=3) and CP (n=17). One way ANOVA; degrees of freedom= 2, 28; F= 2.50, P-Value= 0.099.

Eggshell thickness of doves was related to the egg volume. Laughing doves have the thinner eggshells and egg volume compared with collared doves and cumulet pigeons (Figure 6.20). Within the laughing doves the thickness of eggshells increased as the volume of eggs increased, while there was no relationship in either cumulet pigeons nor collared doves (Figure 6.20).

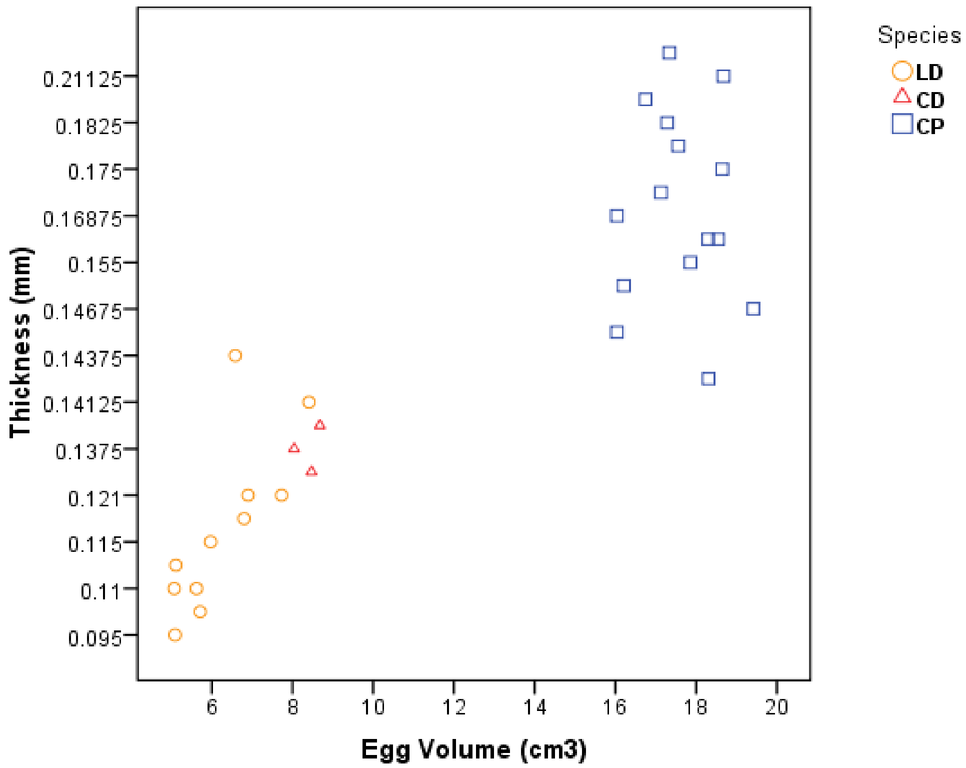


Figure 6.20 Relationship between eggshell thickness and egg volume within different doves. Mean egg volume; laughing dove (LD) 6.27 ± 0.34 cm^3 and collared dove (CD) 8.40± 0.19 cm^3 from Kuwait, cumulet pigeon/domestic pigeon (CP) 17.61 ± 0.27 cm^3 from United Kingdom. Sample size (n=29): laughing dove (n=11), collared dove (n=3) and cumulet pigeon (n=15). There is clearly no relationship in the cumulet. Correlations between shell thickness and eggshell volume of laughing doves: sample size= 11, Pearson Correlation = 0.760, sig, (2-tailed)= 0.007. the collared dove sample is too small for meaningful analysis.

There was a trend of reduction in water loss as thickness of laughing dove eggshells increased. At 34°C, the correlation was insignificant (Figure 6.21). But, at 40°C it was close to significant (Figure 6.22). In addition, this correlation was also insignificant when it was done for each species separately.

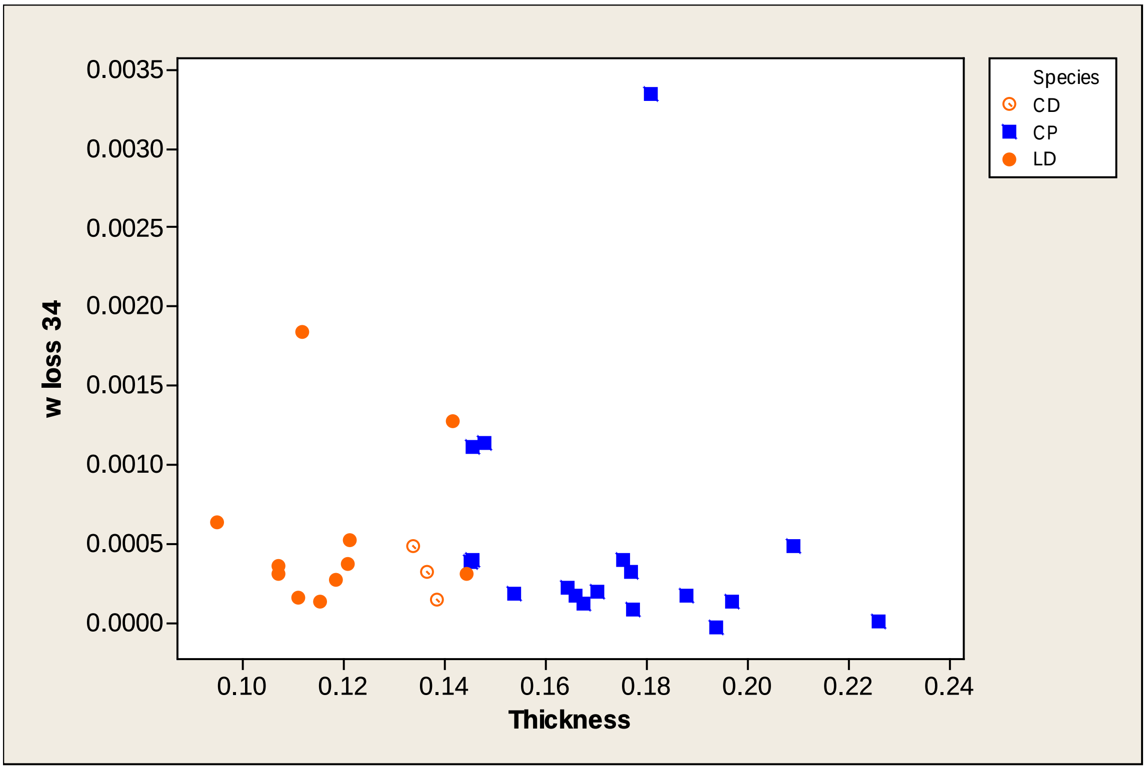


Figure 6.21 The relationship between water loss and eggshell thickness within different doves at 34°C. Scatter values of laughing dove (LD), collared dove (CD) and domestic pigeon (CP). Sample size (n=32): laughing dove (n=11), collared dove (n=3) and cumulet pigeon (n=18). Pearson correlation= -0.048, P-Value = 0.793.

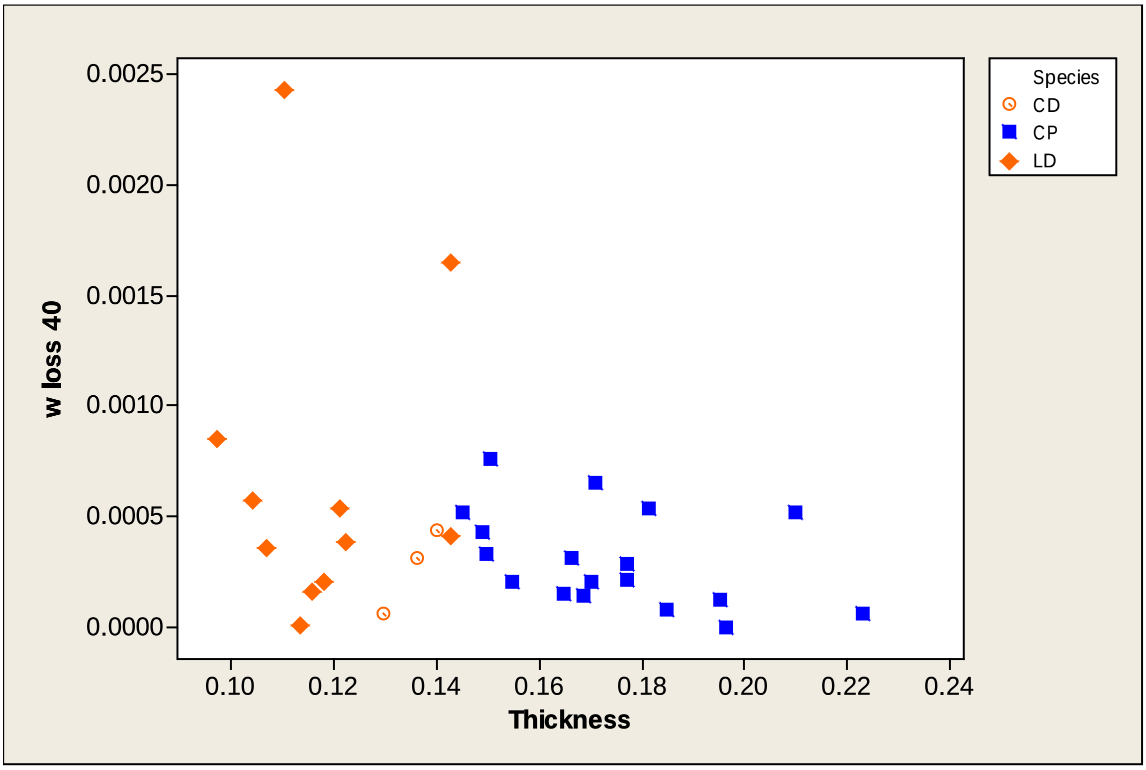


Figure 6.22 The relationship between water loss and eggshell thickness within different doves at 40°C. Scatter values of laughing dove (LD), collared dove (CD) and domestic pigeon (CP). Sample size (n=32): laughing dove (n=11), collared dove (n=3) and cumulet pigeon (n=18). Pearson correlation= -0.330, P-Value = 0.065.

At neither 34°C nor 40°C incubation temperature was there a significant correlation between water loss and egg volume (Figure 6.23).

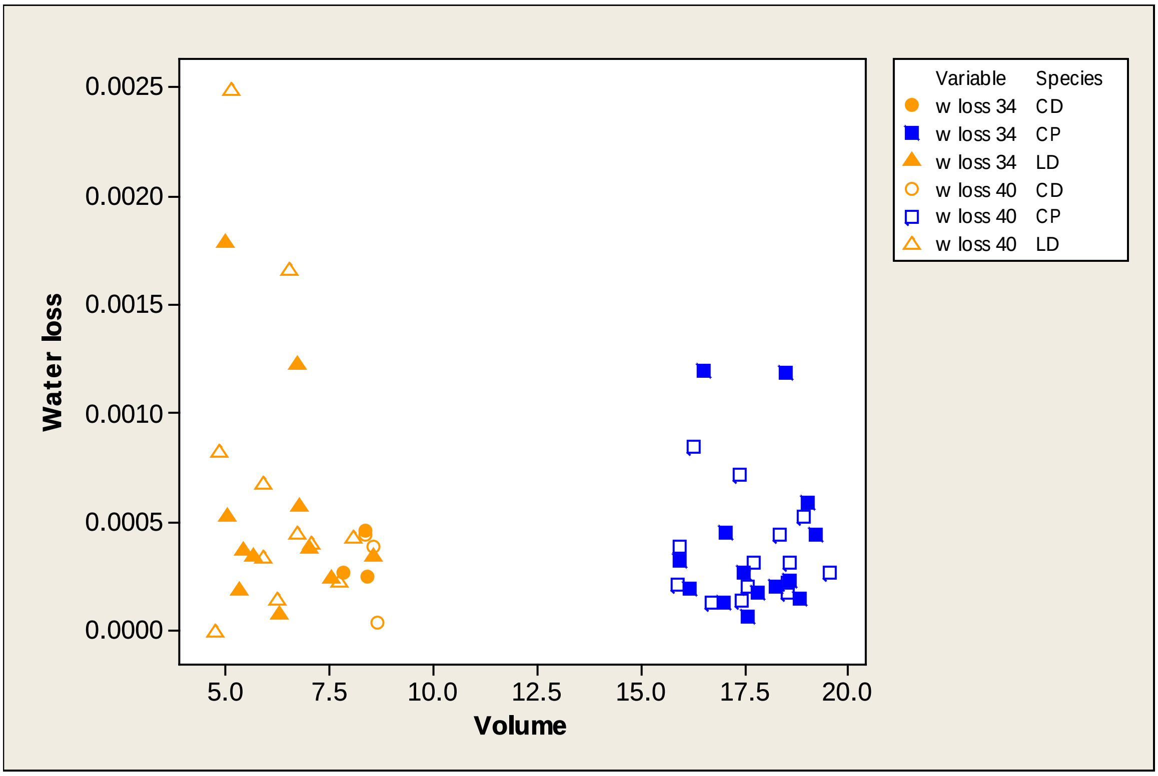


***Figure 6.23** The relationship between water loss and egg volume within different doves. Scatter values of laughing dove (LD), collared dove (CD) and domestic pigeon (CP). Sample size (n=32): laughing dove (n=11), collared dove (n=3) and cumulet pigeon (n=18). over all Pearson correlation= -0.317, P-Value = 0.094. In laughing dove (LD) n=11, Pearson correlation= -0.255, P-Value = 0.448 at 34°C and = -0.287, P-Value = 0.393 at 40°C. In domestic pigeon (CP) n=18, Pearson correlation= -0.096, P-Value = 0.732 at 34°C and = - 0.201, P-Value = 0.472 at 40°C.*

Within species:

House sparrows

Egg volume of house sparrows increased with latitude. Samples from low latitude (Kuwait) have smaller egg volume than high latitude samples (England and Scotland) (Figure 6.24).

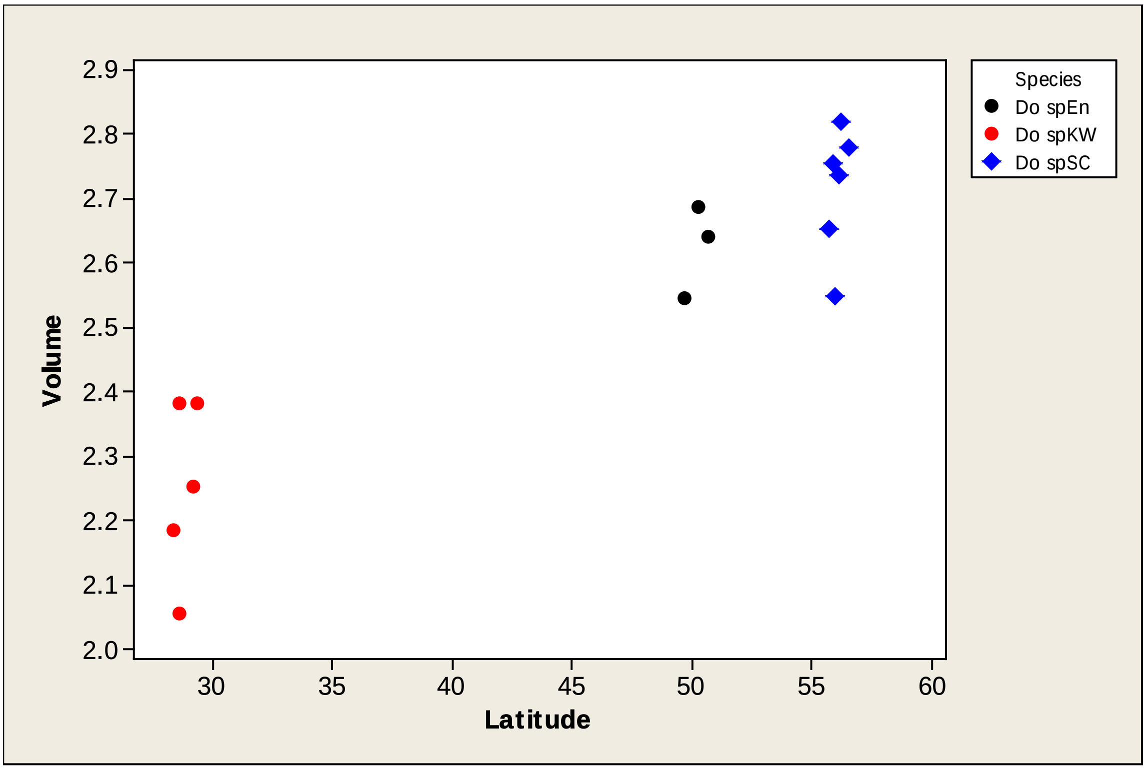


Figure 6.24 The relationship between egg volume of house sparrow and latitude. Sample size (n=14): Kuwait house sparrow (Do sp KW) n=5, England house sparrow (Do sp En) n=3 and Scotland house sparrow (Do sp SC) n=6. Pearson correlation= 0.905, degrees of freedom=2, 12, P-Value= 0.0001

House sparrows showed a significant difference in the eggshell thickness between Kuwait and the United Kingdom.

Colour pigments of the house sparrow did not show any significant differences between Kuwaiti, English and Scottish samples. All geographical samples have a wide variance in ground colours and speckle colours. The visible colours of their eggshells seem to be similar, at least to human eyes. Their photographs were not analyzed by computer program, but examined by naked eye, due to limited time. Both Kuwaiti and British house sparrow eggshell have a wide range of colours. Both of them showed off-white colour ground and speckles range from greyish to brown colour.

Also, eggshell thickness of house sparrow varied among Kuwait, England and Scotland. Kuwait samples of house sparrow eggshells were the thinnest on average, while Scottish samples of house sparrow eggshells were the thickest (Figure 6.25). The English samples were intermediate between Kuwait and Scottish samples (Figure 6.25 and 6.26).

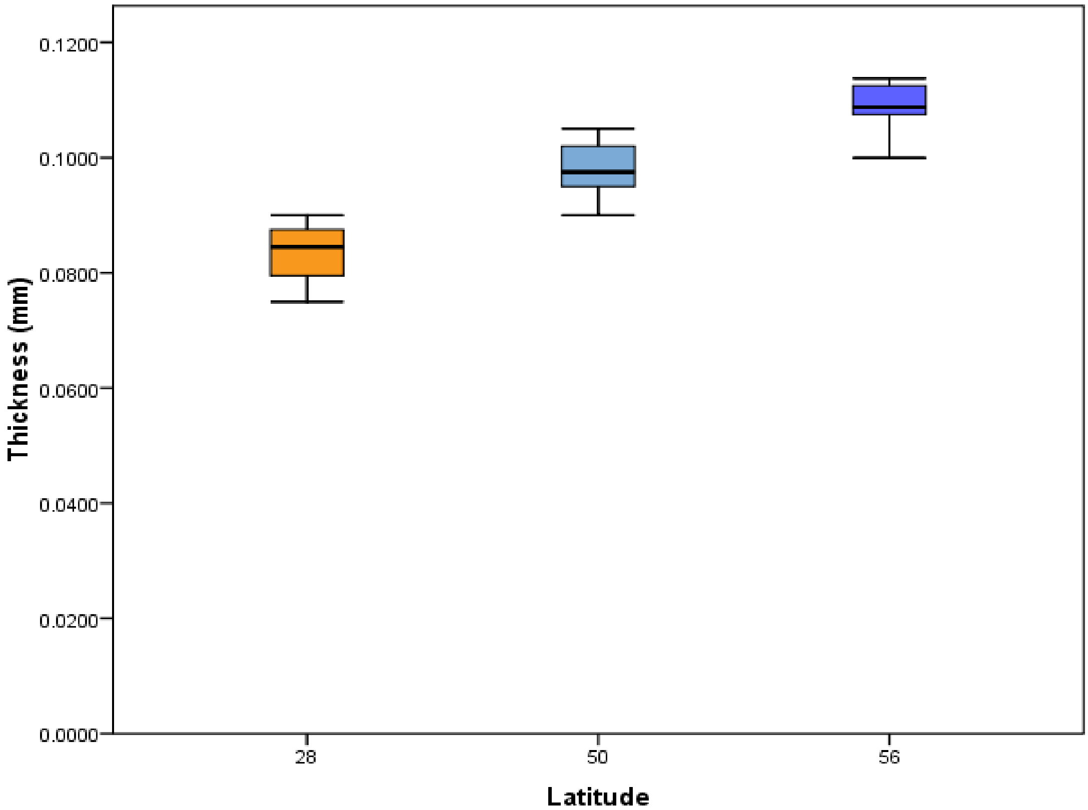


Figure 6.25 Thickness of house sparrow eggshells among low and high latitude. Low latitude Kuwait (n=7), high latitude England (n=6) and very high latitude Scotland (n=6). One way ANOVA; degrees of freedom= 2,16, F= 25.47, P-Value= 0.0001. Furthermore, the shell thickness of house sparrows was significantly different between England and Scotland samples, One way ANOVA; degrees of freedom= 1, 11, F= 12.88, P-Value= 0.005.

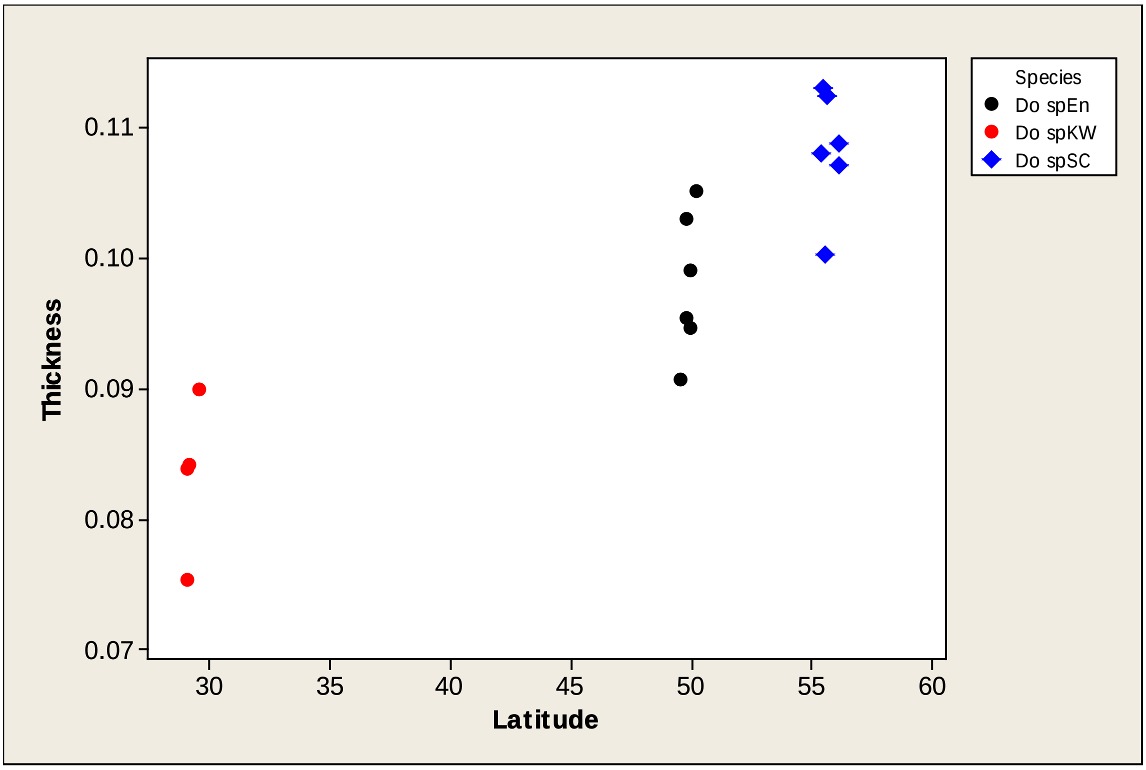


Figure 6.26 A scatter plot of affect of latitude on shell thickness of house sparrow. Sample size (n=19), Kuwait house sparrow (Do sp KW) n=7, England house sparrow (Do sp En) n=6 and Scotland house sparrow (Do sp SC) n=6. Pearson correlation of Thickness and Latitude= 0.864, P-Value= 0.0001

My results are again consistent with Ar and Rahn (1985). They found eggshell thickness of house sparrow equal 0.100mm which is thicker than Kuwait samples which again consistant with an increase in eggshell thickness with latitude where Tel-Aviv and Buffalo are higher latitude zones than Kuwait.

There was a significant difference between the water loss of the eggshells of Kuwaiti, English and Scottish house sparrows. The eggshell of Scottish house sparrows has a lower water loss than Kuwaiti and English house sparrows at 34°C (Figure 6.27). Whereas at 40°C temperature, the variation was wider, the eggshell of Kuwaiti house sparrows showed more water loss than English and Scottish house sparrows in comparison to incubation at 34°C temperature (Figure 6.28).

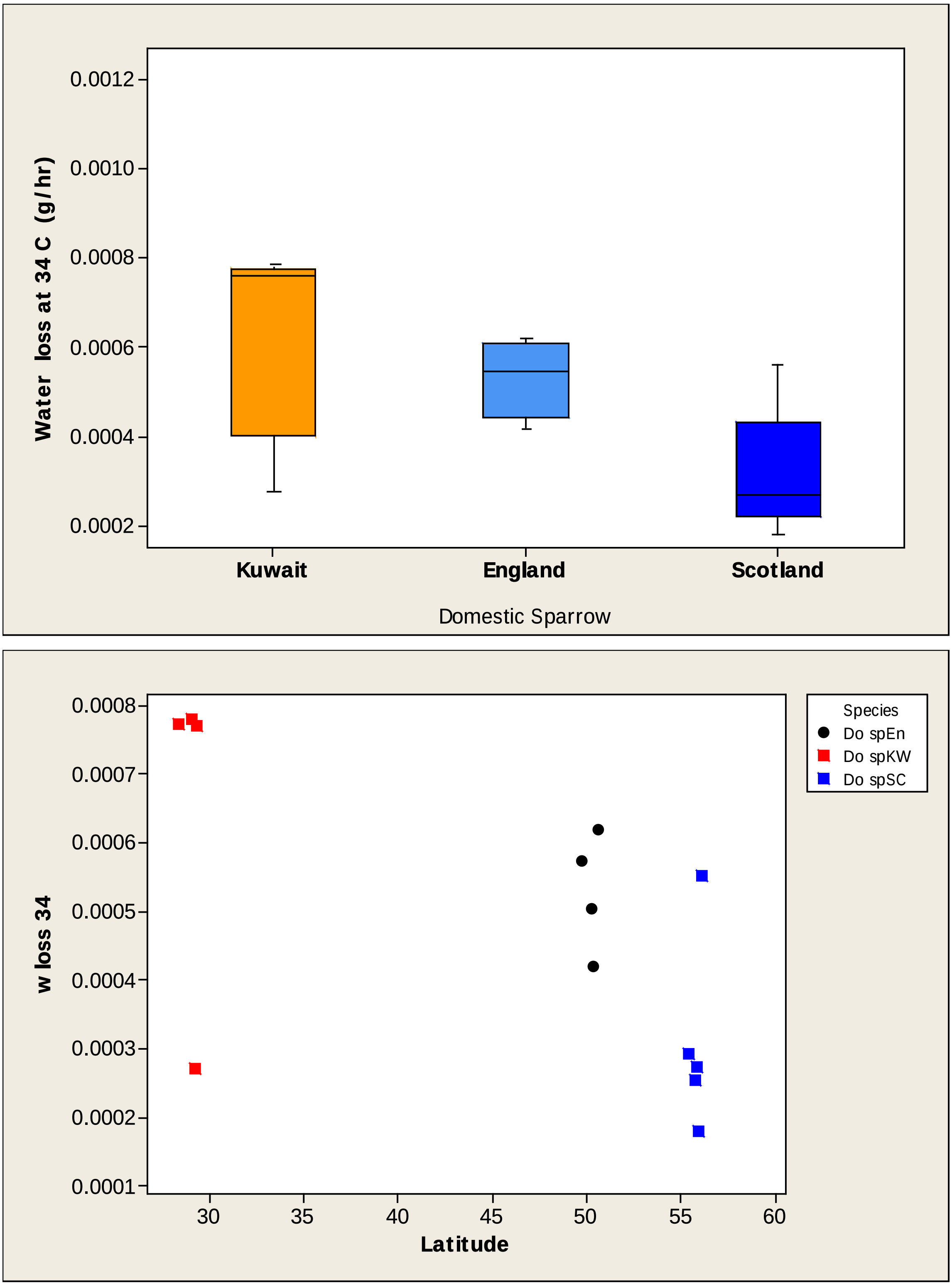
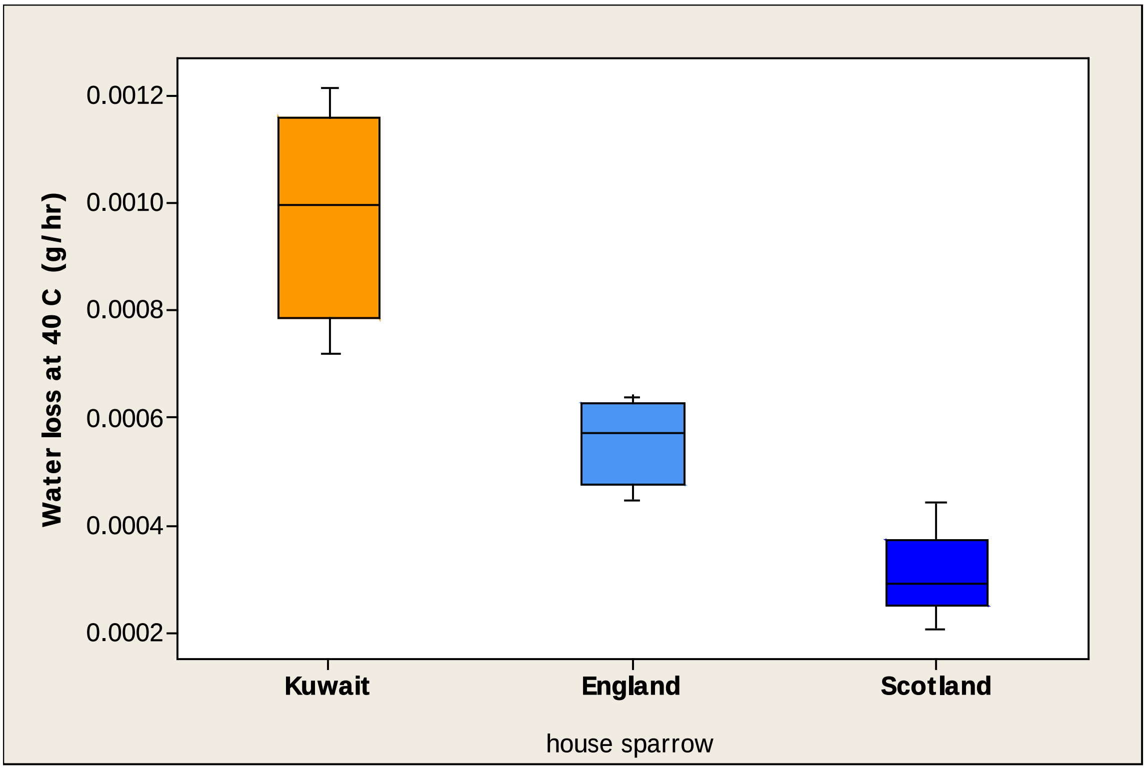


Figure 6.27 A comparison of water loss between Kuwaiti, English and Scottish house sparrow eggshells at 34°C. One-way ANOVA: water loss at 40°C versus Species show a significant difference between Kuwaiti (n=4), English (n=4) and Scottish (n=5) house sparrow eggshells. Degrees of freedom 2, 11, F= 4.53 and P-Value= 0.040.



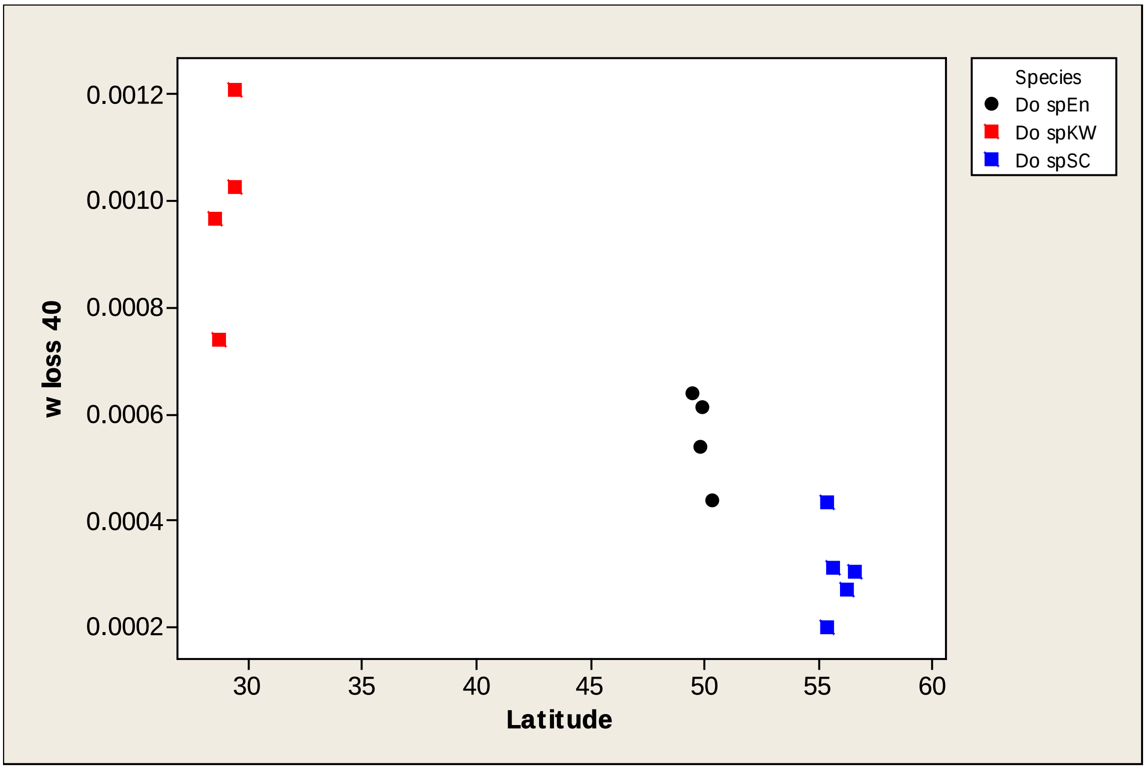


***Figure 6.28** A comparison of water loss between Kuwaiti, English and Scottish house sparrow eggshells at 40°C. One-way ANOVA: water loss at 40°C versus Species show a significant difference between Kuwaiti (n=4), English (n=4) and Scottish (n=5) house sparrow eggshells. Degrees of freedom 2, 11, F= 30.13 and P-Value= 0.0001*

There was a significant relationship between water loss and egg shell thickness (Figure 6.29 and 6.30).

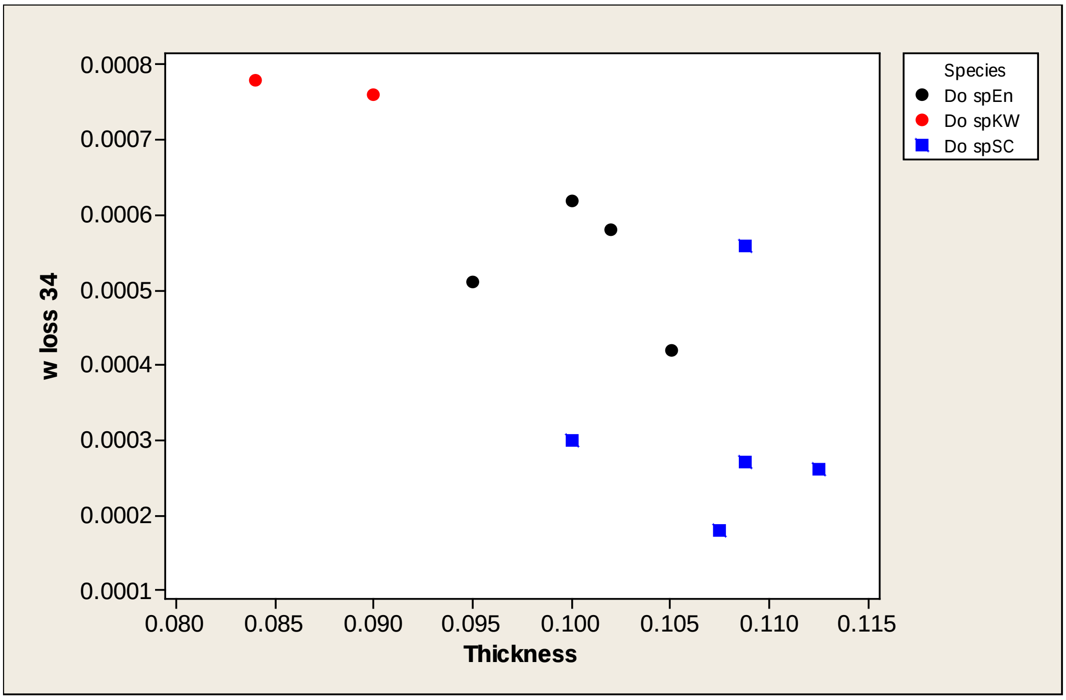


Figure 6.29 The relationship between water loss at 34°C of house sparrow eggshells and thickness. Sample size (n=14): Kuwait house sparrow (Do sp KW) n=5, England house sparrow (Do sp En) n=3 and Scotland house sparrow (Do sp SC) n=6. Pearson correlation= -0.777; degrees of freedom=9, P-Value= 0.01.

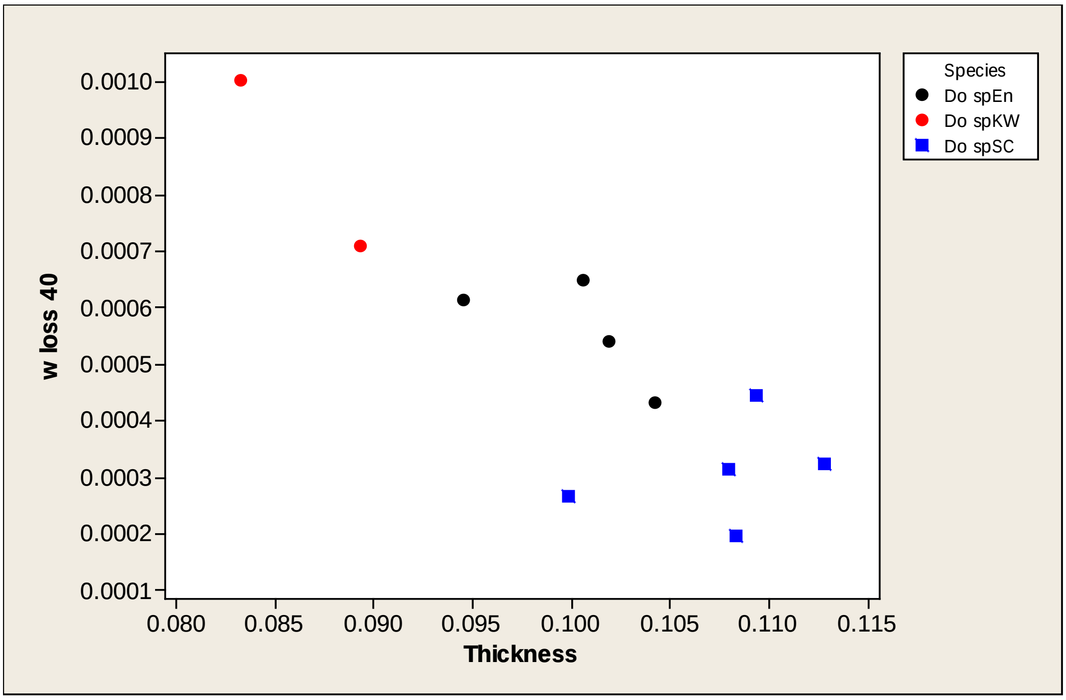


Figure 6.30 The relationship between water loss at 40°C of house sparrow eggshells and thickness. Sample size (n=14): Kuwait house sparrow (Do sp KW) n=5, England house sparrow (Do sp En) n=3 and Scotland house sparrow (Do sp SC) n=6. Pearson correlation= -0.874; degrees of freedom=12, P-Value≤ 0.001.

Overall relationships show a significant correlation between water loss and eggshell thickness (Figure 6.31).

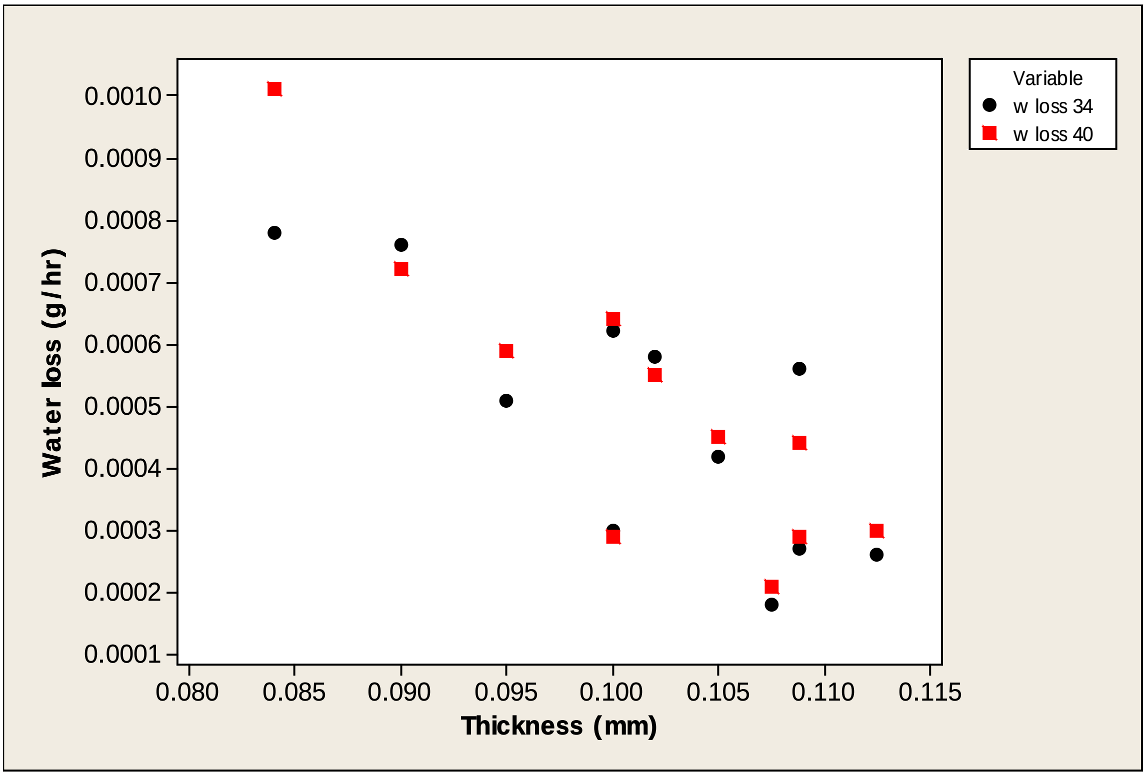


***Figure 6.31** The overall relationships between water loss at 34°C and 40°C of house sparrow eggshells and thickness. Sample size (n=14): Kuwait house sparrow (Do sp KW) n=5, England house sparrow (Do sp En) n=3 and Scotland house sparrow (Do sp SC) n=6. Spearman's Correlation co-efficient= 0.013 at 34°C and 0.049 at 40°C.*

Water loss was significantly correlated to egg volume (Figure 6.32 and 6.33).

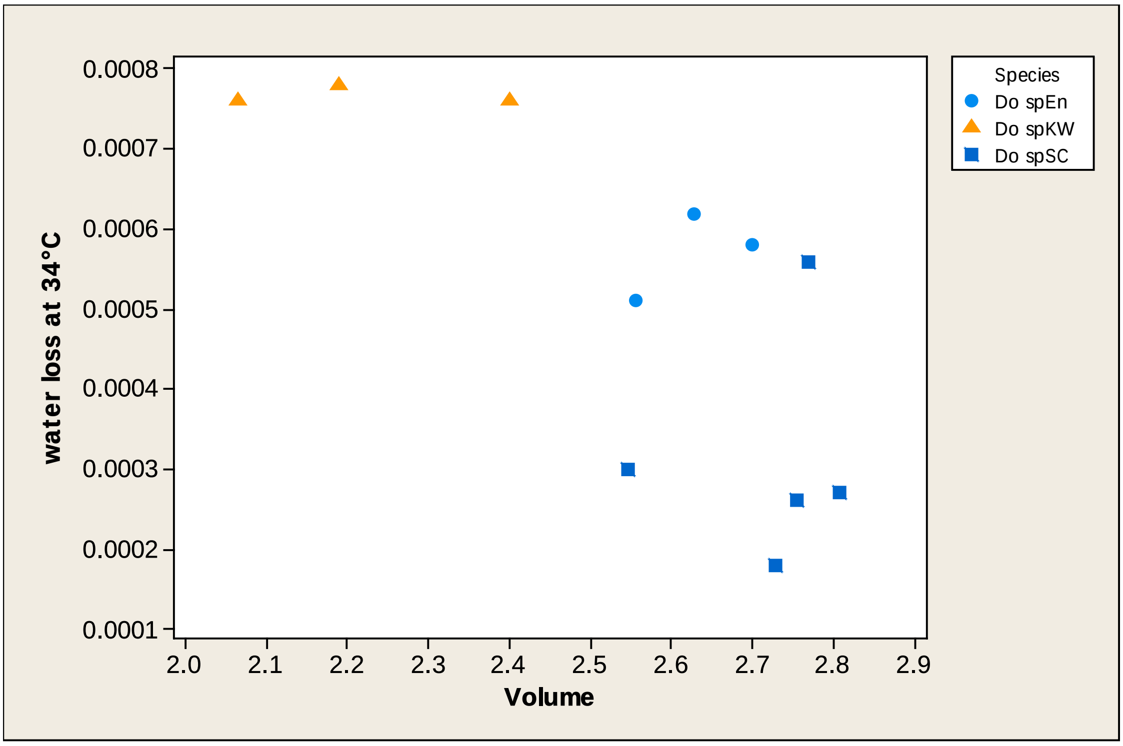


Figure 6.32 The relationship between eggshell water loss at 34°C and egg volume of house sparrow. Sample size (n=14): Kuwait house sparrow (Do sp KW) n=5, England house sparrow (Do sp En) n=3 and Scotland house sparrow (Do sp SC) n=6. Pearson correlation= -0.730, degrees of freedom= 12, P-Value= 0.011.

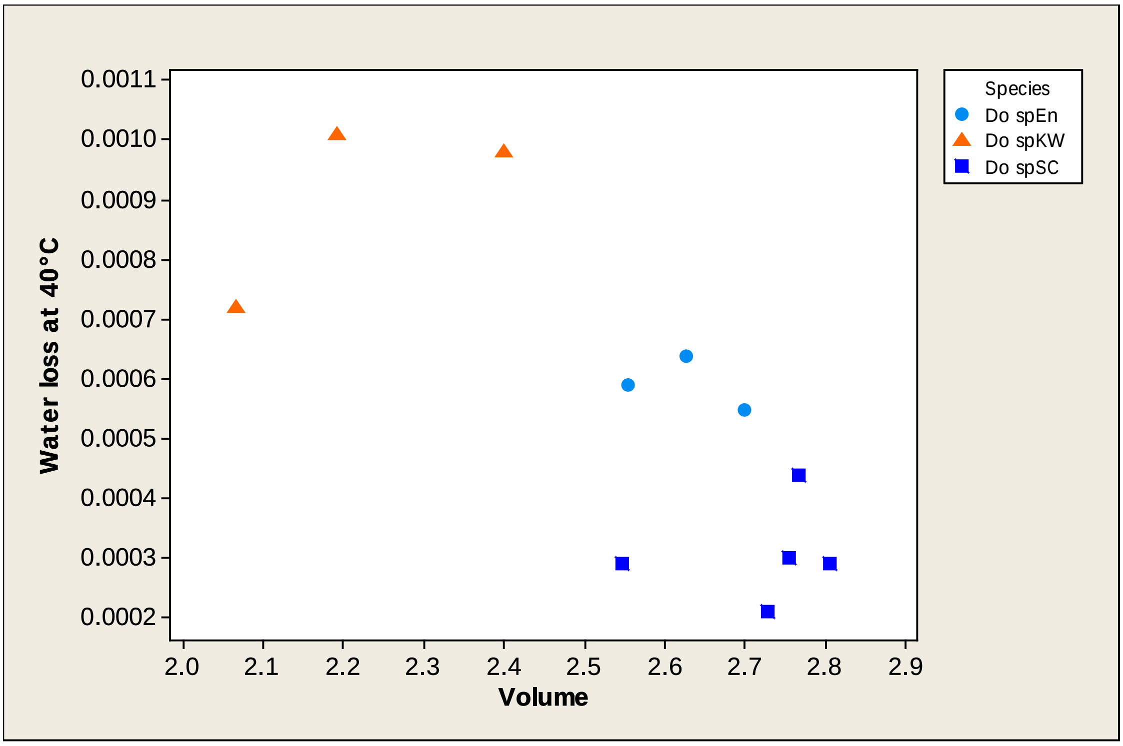


***Figure 6.33** The relationship between eggshell water loss at 40°C and egg volume of house sparrow. Sample size (n=14): Kuwait house sparrow (Do sp KW) n=5, England house sparrow (Do sp En) n=3 and Scotland house sparrow (Do sp SC) n=6. Pearson correlation= -0.749, degrees of freedom=12 , P-Value= 0.008.*

6.4 Discussion

My analysis reveals some variations in the eggshell characteristics of larks in response to temperature and latitude. However, conditions at a given latitude might also vary and it would be instructive to include other factors such as nest location, shade, solar radiation, wind, bird behaviour, humidity, etc but I did not have the sample size, or the detailed information, to do this in my study, but I discuss the likely influence of such factors below.

Desert birds would be expected to have evolved special characteristics that allow their eggs to tolerate the warm and arid environment. Incubation in hot, dry climates is believed to consume more water than in a cold, wet climate (Ar & Rahn 1985). It was expected that eggshells of larks in arid regions would have less water conductivity than those in temperate regions to save water content of the egg. But this is not what my results showed. Eggshells of desert species have more water loss than those of closely related temperate species as an adaptated response to habitat ecology, which is contrary to Ar and Rahn (1985) who expected sand partridge *Ammoperdix heyi* and black-billed sandgrouse *Pterocles orientalis* as desert nesters to have lower pore density and water conductance than the more humid nesting pied-billed grebes *Podilymbus podiceps* and western grebes *Aechmophorus occidentalis* which nest in water soaked vegetation. Maybe, water loss from desert species' eggs functions to moisten the incubation environment uder the brood patch.

Species with ‘hot habitat’ ecology compensate for high temperature by losing more water content in comparison with temperate species. Eggs of crested larks are supposed to have higher initial water content than skylark eggs to avoid dryness in an embryo. Water content of fresh crested lark eggs= 83.0% (n=3) & hatchling = 83.6% (n=1) (Ar & Rahn 1985), but no data were found about skylark egg water content. My results showed that crested lark eggshells have more water conductance than those of the UK skylarks.

Thickness of crested lark eggshells in my results was thinner than Ar and Rahn (1985) results. They found eggshell thickness of crested larks equal 0.100mm which is thicker than my result (0.07956 ± 0.00201mm). Unfortunately, they did not specify exactly the resource of egg samples according to the latitude, but they classified their data according to published or non published and researcher sources. Hence, they combined unpublished lab results of Tel-Aviv, Palastine and Buffalo, USA samples together. However, both these sites have higher latitudes than Kuwait.

My results show an increase in the eggshell thickness with latitude and toward temperate regions. The thickness of eggshells was consistent with water conductance in lark species. Water loss is inversely proportional to the eggshell thickness (Ar & Rahn 1985). Hence, an increase in the eggshell thickness of skylarks will reduce its water loss. Crested larks have thinner eggshells and more water conductance than skylarks. Water conductance can vary due to different thicknesses of eggshells and also as a result of more pores in the eggshell surface. Hence, eggshells of crested larks might have denser or/and wider pores than skylark eggshells. Further studies would be required to examine this.

Intensity of colour pigments can affect the percentage of transmitted light through the eggshell. Shafey *et al*. (2004) found dark brown pigments of eggshell reflect less light in the near infra-red band. Consequently, dark brown pigments are better (to warm the eggs) in case of unattended eggs within cold habitats. Whereas, in hot habitats light brown pigments are better to avoid over heating by solar radiation (Bakken *et al.* 1978) which is associated with infra-red.

In comparison to dark brown pigments, light brown pigments permit more light to be transmitted through the eggshell. The transmission of light across the eggshell increases as the intensity of eggshell pigment decreases (Shafey *et al.* 2004). Light brown pigments reflect about half amount of visible and ultra-violet light (in the equator region and 2/3 times in the poles) than dark brown pigments do (Shafey *et al*. 2004). Hence, eggs of crested larks will acquire more light (about 2 times in the equator region and 1.5 times in the poles) than skylark eggs. This means eggs of crested lark will be vulnerable to more threat of heat gain, particularly in hot desert climate such as Kuwait.

However, the heat gain in an egg depends on several things other than intensity of pigment colour alone. Dimension of eggs, active pores, pore density, eggshell conductance and percentage of shaded incubation can influence the amount of transmitted light to the embryo (Shafey *et al*. 2005). Percentage of a nest cover may differ between a crested lark and a skylark. Crested larks nest under vegetation with around 80% of shade (Chapter 5). Under shade, eggs with light pigmented brown shells were more affected by high intensity of light than middle and high pigmented brown shells (Shafey *et al*. 2005).

Infra-red light, which is related to heat accumulation, is more harmful for eggshells than ultra violet and visible light. Consequently light brown pigment is an advantage attribute for crested lark eggshells to avoid infra-red light in sunny habitats in the thermal environment. Hence, light-colored eggs gain heat slower than dark eggs, and being less threat to overheating and thermal dehydration. Furthermore, light brown pigment provides more illumination during incubation which improves hatchability of eggs (Shafey *et al*. 2005).

My results showed that crested larks have eggshells with higher conductance and transmission of light than skylarks. This is consistent with Shafey *et al's*. (2002) results that correlate water conductance with light transmission. They found eggshells with high water conductance transmit more light. Also, they considered the eggshell conductance as a good indicator for eggshell ability to transmit light. Which means the darker pigment colour an egg has the less water conductance it will has.

Variation in colour pigments of two sibling species; skylarks and crested larks coincides with Cassey *et al*. (2010) who found species within the same family have different light reflectance in the medium wavelength. He considered this variance as a species specific adaptation corresponding to nest site selection and behaviour.

My finding confirms McCormack and Berg's (2010) results that concluded more dark pigmented eggshells at high elevation have less light reflectance. This could prompt an eggshell to absorb more solar radiation to warm the embryo in cool regions. Crested larks had white-off to light milky background eggshells with small light brown spot pigments. In contrast, skylark eggshells appeared as light olive background with dark brown spots (Figure 6.34). My skylark observation was consistent with Kennedy and Vevers (1976) results who described the colour of skylark eggshells as off-white; olive or brown speckles. They also, found fluorescence, protoporphyrin and a trace of biliverdin in skylark eggshell pigments. Precentage of fluorescence and biliverdin may differ between skylarks and crested larks. For instance, high variability of the porphyrin content in intra-species (Eggs of the red-backed shrike) is likely to express physiological effects of nesting conditions and the environment status (Miksik *et al* 1994). Unfortunately, I was not able to measure fluorescence, protoporphyrin and biliverdin amounts in crested lark eggshells.

Eggshells of Kuwaiti, English and Scottish house sparrows may vary their fluorescence and protopophyrine or may not vary because their nests are closed and not facing direct sun light.

My results show that crested larks and house sparrows have similar eggshell thickness. According to Ar and Rahn's (1985) results both crested larks (n=12) and house sparrows (n=9) have the same length of pore (100µm), but they differ in the number of pores per egg. A crested lark has 917 pores per egg while a house sparrow has 440 pores per egg (Ar & Rahn 1985). Equivalent length of pores could mean same eggshell thickness for our two passerine species; crested lark and house sparrow. Double the number of pores in crested larks compared with house sparrow may compensate for nest micro habitat environment. An enclosed nest style protects eggs of house sparrow from direct sun light and consequent overheating and water evaporation which open nest species such crested larks face. Crested larks have higher water conductance 0.92mg/d.torr than house sparrows 0.74mg/d.torr (Ar & Rahn 1985). However, water conductance (rate of water loss) within the same species influenced by the humidity of a season. In humid seasons, water conductance of naturally incubated eggs is 25% less than in dry seasons (Walsberg 1985). This high water conductance of an open nest species, crested lark mitigate the risk of high temperature and help to cool the egg in hot desert or semi-arid areas.

Since the water conductance of an eggshell is proportional to its pore density "number of pores" (Ar & Rahn 1980). One may assumed that crested larks have more pore density than skylarks in their eggshells. But, this should not be necessary where I found eggshell of crested larks are thinner in thickness in comparison to skylarks. Furthermore, crested larks have larger active pore area than skylarks in their eggshells. Where active pore density *Ap* of crested larks 2 to 3 times skylarks. Hence, further studies are needed to distinguish between the possibility of whether size or number of pores differs between crested lark and skylark eggshells. This can be done by counting pores of eggshells of those two sibling species.

Some studies found that egg shape of a species become more spherical towards high latitudes (Encabo *et al*. 2002) to increase the eggshell strength (Sabath 1991, Kratochvil & Frynta 2005). Accordingly, one would predict skylarks have more spherical eggshells than crested larks. In addition, measuring a fragile pieces of skylark eggshell samples was risky, especially the museum sample. The risk here when an eggshell sample being cracked or defragmented into small pieces neither one will become suitable to place on the eppendorf. To investigate any differences in the egg shape of crested larks and skylarks a reasonable sample size of whole eggs will be necessary.

Despite of small sample size of skylark eggshells that I obtained and the difficulty of measuring their lengths and widths where eggshells were halves, my results were consistent with the limited published papers on skylark egg volume. Unfortunately, I did not find other data on egg volume of crested larks in the literature. However, egg volume of skylarks in my results and in literature reviews (e.g. in United Kingdom; Snow & Perrins 1998 and Harrison 1975 and in Spain; Suárez 2005) tend to be greater than the egg volume of Kuwait crested larks in my results.

Sibling dove species showed difference in eggshell thickness between arid and temperate zone, where the former is thinner than the latter. One may expect that thickness of eggshells varies between different species and increases as the egg size increase. However, my results show that the eggshell of Kuwait laughing dove (0.117mm) is thicker than the same species (0.088mm) in southern Africa (Steyn *et al*. 1986). This is compatible with my previous results that the eggshell thickness increases as the latitude increase. In addition, average length (27.0 mm) and width (21.0 mm) of laughing dove eggshells were bigger than south Africa samples (25.78 mm) and (19.97 mm) respectively. Hence, egg volume of Kuwait laughing doves is larger (6.09 cm^3) than South Africa (5.24 cm^3). This result coincides with my earlier results that egg volume increases with latitude. My results did not show any significant difference between water loss of sibling dove species which may relate to their different egg volume sizes. However, Walsberg and Schmidt (1992) found that newly laid mourning doves *Zenaida macroura* eggs lost significantly less water than those in intermediate or arid areas.

In view of the fact that the laughing dove is a widespread breeding species, it would be worth examining their eggshell characteristics among different regions (temperate/arid zones). Further studies on thickness, water loss and body shape (elongated/spherical) will improve our knowledge about species adaptation as a consequence of habitat or climate differences in ecological regions. For instance, a variation in thickness of laughing dove eggshells may serve to test the hypothesis of eggshell thickness and altitude/ latitude.

Kennedy and Vevers (1976) described the colour of house sparrow *Passer domesticus* eggshells as off-white; grey-brown markings. They found fluorescence, protoporphyrin in house sparrow eggshell pigments. Miksik *et al.* (1994) also found protoporphyrin (4.87nmol and 48.4pmol/mg eggshell) but zero biliveredin. Could protoporphyrin differ between the same species to play a role in light reflectance to reduce the effect of solar radiation or is it just related to other biological metabolisms in the egg? Again in my samples I did not examine the presence of such trace compounds.

Significant difference between water loss of Kuwaiti, English and Scottish eggshell house sparrows confirms the effect of latitude on eggshell conductance. More studies based on large sample size are needed to eliminate the effect of extreme or abnormal samples.

Overall, my results suggest that there are important changes in egg shell structure that appear to be related to habitat differences. The extent to which the differences I observed are related to theremal conditions, as opposed to other additional factors, requires further study.

Chapter 7: Conclusion and Conservation Issues

The results were consistent with protection offering conservation benefits to vegetation and chosen indicator species (larks) in Kuwait State. Habitat quality and biodiversity richness in non protected areas were very low in comparison to protected areas. Distribution and abundance of the lark family *Alaudidae,* and the crested lark *Galerida cristata* in particular, were announced to be a key habitat indicator.

The assessment of the vegetation cover and the plant species richness reveals the effect of human activity factors (such as grazing, camping, hunting, etc) on land degradation. Vegetation is a powerful indicator of land degradation in Kuwait. Richness of plant species was correlated negatively with land degradation. Floral families and species in protected areas were between 2 and 10 times those of open areas. The richest open area (R-Kabd) maintained half the floral species richness compared with (Kabd) protected areas, whereas the worst open area (B-SAANR) showed one-tenth of flora species richness in (SAANR) protected area. This remarkable variance shows the important role of protected areas.

Significant difference of vegetation cover and its component species between protected and unprotected areas requires decision makers to develop a national strategy to preserve ecosystems. Open areas need some powerful regulations to reduce their degradation. Legislation regulating camping, grazing and other human activities should be revised and enforced to conserve open access areas. Otherwise, premature death of plant species will reduce their individual numbers and their chance to appear in subsequent years (Brown & Schoknecht 2001). Extensive degradation will need prolonged and intensive remediation especially in dry environments and shallow soils

(Brown 2003). Consequently, desertification is irreversible without replanting even after 25 years of total protection (Le HoueHrou 1996). Open rangelands demand a new strategy to rehabilitate ecological habitats. For example, restrictions on camping and grazing in Bahrain and Saudi Arabia contributed in protecting habitat ecology of open areas where one can now see nests of breeding species such as larks. In Qatar, powerful pronouncement of environmental legislations facilitated gazelle and rabbit release in open areas. It is now possible to see the wildlife species again in the desert in these areas after a long period of absence (about 6 decades).

Lark species were used as indicators to measure the benefit of the current conservation measures in Kuwait. There was a significant difference between lark density and species richness in protected, non-protected and arable lands. Density of larks was very low in non-protected areas. An obvious conclusion from the results was the important role of protected areas in the conservation context. Absence of territories, mating signs and nests of crested larks in B-SAANR was a strong evidence of its poor quality area in comparison to inhabited areas. Native shrubs such as *Haloxylon salicornicum, Rhanterium epapposum, Stipagrostis plumosa* and *Zygophyllum qatarense* can be implanted in the desert according to their previous distribution to rehabilitate the ecosystem of open lands (Halwagy & Halwagy 1974).

Species diurnal use of Talha water hole reveals the important role a water hole can play. Talha water hole became an essential spot for the attraction of most biodiversity in the SAANR, especially in summer. In dry seasons, access to water is crucial for wildlife species in desert areas. The data collected demonstrated the importance of the water hole and its structure for the bird community and biodiversity. Establishment of some other water holes ringed by trees will increase the total water surface area and biodiversity richness. In addition, water holes could be useful to check for successful breeding during late spring and early summer by recording the number of juveniles drinking water or shading near the water hole. This method was used to monitor breeding success of wildlife. One example in the western Netherlands, raptors, corvids and owls were monitored within the 3400 ha of the Amsterdam Water Supply Dunes during 1961 to 2007 (Koning *et al.* 2009). In south-central New Mexico during 2002 video surveillance was used to assess species visitation such as mourning doves *Zenaida macroura* at free-choice quail feeders and guzzlers (Rollins *et al*. 2009). They recommend examining the potential ability of video surveillance at guzzlers to estimate chicks' survival. For small passerine species such as songbirds, insectivores and nectarivores, which are difficult to locate or check their nests, their annual breeding success (presence of their juveniles) might be observed at water holes. Another example was in the Sonoran Desert, southwestern Arizona, USA, where wildlife use of 3 water catchments were counted by video surveillance equipment to document the biodiversity (O'Brien *et al.* 2006). Throughout 3 years, they found the peak visits of water catchments during June and July and recorded 34 game and non game species while drinking water, bathing, consuming plant material and carrion or animal interacting. Hence, constructing water hole in desert lands is believed to improve wildlife survival and diversity and to provide a useful monitoring tool.

The breeding survey showed that larks face environmental challenges to breed in Kuwait. Absence of nests in unprotected areas B-SAANR and R-Kabd were correlated with their poor vegetation cover. Poor vegetation cover was associated with extremely high ambient temperature.

Arable lands can compensate for poor vegetation cover in open areas and rain shortage in protected areas. The Pivot farm as an example of arable lands became a hot spot for biodiversity. Presence of crops and water attracted numerous wildlife species to inhabit its land and breed. Its alfalfa and barley crops encouraged many pairs of crested larks to breed. The Pivot farm possess potential characteristics that are absent in open areas and protected areas. Crested lark were found mostly nesting in arable lands to compensate for poor habitat quality, weak vegetation cover and rainfall shortages in protected areas. But, greater hoopoe larks and bar-tailed lark did not inhabit or breed in arable lands. When habitat degradation coincides with rain shortage, both greater hoopoe larks and bar-tailed larks will be deprived of breeding opportunities. Consequently, they may face potential extinction in Kuwait due to their incapability to breed or continued unsuccessful breeding attempts. My results confirm that local farming management is important to protect grassland bird abundance (Batary *et al.* 2007). Crested larks shifted their breeding to more stable vegetation habitats (in arable lands) supporting Butter's idea that bird species displace their ranges in response to warming temperature and predation/prey competition (Butler *et al.* 2007). Presence of high biomass soil invertebrates e.g. earthworms due to both dung and soil-dwelling in the Pivot farm encourage crested larks to breed. Implantation of *Rhanterium epapposum*, *Haloxylon salicornicum*, *Zygophyllum qatarense* and *Stipagrostis plumosa* shrub species in vicinity of crops and in remote areas of arable lands may attract and encourage greater hoopoe larks and bar-tail larks to inhabit these areas and breed.

The effect of macro and microhabitat nest site selections on larks and doves thermoregulation was examined to determine the favourable position of nest they prefer which might help when management aims to provide artificial shade to encourage them to breed. Northeast orientation possibly shows the most reasonable temperature within the breeding season March-May. All ground nest orientations showed extreme high temperatures during midday within late May and early June in desert open land habitats. Site location showed a considerable difference between temperature of ground nest and tree nests. This temperature difference between these two microhabitats: ground and tree nests explains why larks' breeding ceases in semi-arid areas during summer, while house sparrow and doves continue to breed. The Pivot farm presents a good alternative habitat for crested larks to breed until mid-June. Humidity and texture of crops in arable lands play an important role in nest thermoregulation. Pivot farm temperatures were lower than SAANR (semi-arid desert PA). Thus, incubation effort of a crested lark nesting in barley or alfalfa crops is less than in desert lands. Temperature remained almost constant within suitable limits in barley nests during early June even without incubation in comparison to alfalfa nests. Thus, an expansion of growing crops in more areas is a supplementary manner to conserve larks and other avifauna as well.

A comparison of components of egg shell morphology reveals the presence of morphological and structural differences both between sibling species, and within the same species, collected at different latitudes. Two sibling species, crested larks *Galerida cristata* (from Kuwait) and skylarks *Alauda arvensis* (from the United Kingdom) have different egg volume, shell pigmentation and colour, thickness and water loss through the shell. Within the same species, the house sparrow *Passer domesticus,* variation in eggshell thickness was also found between birds from Kuwait and the United Kingdom.

These results suggest local adaptation in eggshell structure. Hence, conservation of wild life and re-introducing the locally extinct species need to consider characteristics of those species with the environment they will be released into. This suggests that latitude, presumably via the effects of environmental temperature, can influence eggshell structure, since the pattern was similar across the lark species compared with the within species variation in the sparrows.

Future studies

A proposal design is needed to protect breeding larks. For example, providing artificial nests with leeward and other positions on roofs with other implantation of shelter shrubs in appropriate areas.

Knowledge of the eggshell structure (such as pore active area, canal types and pore density) within these species is needed to understand the adaptive significance of having thicker egg shells at higher latitudes. Differences in canal types and pore density may explain why house sparrows show differences in shell thickness but not much difference in water loss. Hence, further studies are needed to distinguish whether size or number of pores differs between crested lark and skylark eggshells. This can be done by counting pores of eggshells of those two sibling species. In addition, number of pores and the active area of pores in Kuwaiti house sparrows and British house sparrow are worth examining.

Eggshells of Kuwaiti, English and Scottish house sparrows may vary in their fluorescence and protopophyrine or may not because their nests are closed and not facing direct sun light. Could protoporphyrin differ between the same species to play a role in light reflectance to reduce the effect of solar radiation or is it just related to other biological metabolisms in the egg?

Water conductance may vary between eggs of crested larks according to habitat of incubation. Incubation in farms provides more humidity than in desert lands. Hence, one can expect less water conductance in eggs incubated in farms. Furthermore, early breeding season (February-

March) is usually more humid than the end of season period (April-May). Consequently, it is important to consider these factors or parameters in future studies. Limited quantitative data on desert bird species such as larks is the challenge a researcher may frequently face. Moreover, eggs' shape might be changed to reduce the ratio between surface (over which they lose water) and volume (water available). Might be worth thinking about what shape minimises surface/volume ratio and see whether Kuwait and non-Kuwait eggs differ in shape in that predicted direction. Comparison between eggshells of the same lark species that breed in an arid region and a temperate region as well may help to explore whether features of variation are due to intra-species differences or due to climate difference as adaptation response.

Recommendations

Arable lands can form important alternative habitats for breeding larks, especially in more arid years. Encouraging the farmers and arable land owners to protect and treat larks as species worth encouraging will facilitate larks' protection and breeding and other species as well. Financial incentives should be provided for those farms that protect wildlife and follow conservation legislation in Kuwait. Declaration and arrangement of annual worthy prizes for best bio-conservative farmers will increase public awareness and encourage farmers to participate in national conservation action plans.

A national action plan is highly recommended to preserve natural habitats and rehabilitate ecosystems by reviewing and controlling hunting, grazing, camping, and other land uses. Conservation of avifauna requires considering their habitat ecology while planning for management of the environment. Hence, vegetation cover preference of avifaunal species varies from family to another. Scattered and low shrubs vegetation around a water hole can provide shelter for crested larks while shading. However, aerial predators follow different tactics than ground predators. Thus, heterogeneity and spaced vegetation cover is preferred for crested larks to permit to have wide field of view and recognize potential predators.

Fragile desert ecosystems need sustainable management, which requires understanding of ecosystem properties. A realistic vision of this management will require rethinking the traditional uses of arid lands and imaginative development programs. Unfortunately, restoration of desert land is a challenge when degradation reaches extreme levels (MacMahon 2000). Hence, uprooted shrubs from large land areas due to overgrazing and extensive vehicle movements will not grow up easily after rainfall, but they need human intervention to plant pre-existing plant species and treat the compaction of soils.

Revision of the status of most lark species *Alaudidae* in Kuwait according IUCN red list is essential. This revision should rely on new updated scientific research evaluations. My study suggested that greater hoopoe larks should be treated as (KW Threat Category: T – Threatened) while crested lark, bar-tail lark and black-crowned sparrow lark as (KW Threat Category: V - Vulnerable). This is based on their population decline and low breeding succees records. Hence, their previous category as ‘low concern species’ according to IUCN is right now not compatible with their current scarcity. The decline in lark numbers needs action plans to secure their natural habitats. Kuwait needs powerful legislations that ban hunting, disturbance of wildlife and destruction of natural habitat as available in the United Kingdom and most Europe Countries and recently in Qatar and Oman. In addition, legislations should be revised to harmonize with the current status of species which may change with time. For example, in spite of considering a crested lark as low concern species throughout most world countries, it was classified as a threaten species according to recent assessment in the United Kingdom.

Appendix 1 Output of TWINSPAN analysis of vegetation data

Number of cut levels: 4

Cut levels:

0.00   20.00   40.00   60.00

Reading data matrix from device 5

WCanoImp produced data file

Input data file :

Title : WCanoImp produced data file

Format : (I5,1X,7(I6,F4.0))

No. of couplets of species number and abundance per line :   7

Number of samples   83

Number of species   46

Omitted species: Omit item   41 Sample   deleted because they are empty

DIVISION   1 (N=   57)   I.E. GROUP *

Eigenvalue 0.858 at iteration   4

INDICATORS, together with their SIGN

Halo x   1(+)

DIVISION   2 (N=   36)   I.E. GROUP *0

Eigenvalue 0.618 at iteration   3

Heli an 1(+)

ORDER OF SPECIES INCLUDING RARER ONES

13 Iflo ga ! 4 Cype rus ! 11 Molt ik ! 21 Rume x ! 29 Lotu s ! 34 Gyna ndr ! 42 Caki le ! 43 Lapp ula

44 Cres sa ! 45 Cale ndul! 12 Arne b d.! 27 Picr is ! 28 Sene cio ! 31 Card uus ! 14 .... . ! 18 Astr ag c

26 Rhan teri! 32 Koel pin ! 33 Rese da ! 35 Bras sica! 36 Trig onel! 37 Sals ola ! 39 Savi gnya! 22 Malv a

6 Lyci um ! 8 Astr ag a! 9 Laun a c.! 16 Alli um ! 20 Emex ! 46 Thre isaa! 10 Laun a m.! 17 Astr ag s

7 Plan tago! 24 Schi sm ! 2 Heli an ! 3 Stip a ! 5 Fago nia ! 23 Neur ad ! 1 Halo x !

ORDER OF SAMPLES

68 Kabid 5 ! 69 Kabid 6 ! 72 Kabid 9 ! 16 SAN 16 ! 70 Kabid 7 ! 71 Kabid 8 ! 73 Kabid 10

64 Kabid 1 ! 65 Kabid 2 ! 66 Kabid 3 ! 67 Kabid 4 ! 22 SAN 22 ! 26 SAN 26 ! 5 SAN 5

7 SAN 7 ! 9 SAN 9 ! 10 SAN 10 ! 36 SAN 36 ! 37 SAN 37 ! 39 SAN 39 ! 11 SAN 11

35 SAN 35 ! 29 SAN 29 ! 25 SAN 25 ! 31 SAN 31 ! 34 SAN 34 ! 38 SAN 38 ! 1 SAN 1

2 SAN 2 ! 3 SAN 3 ! 6 SAN 6 ! 24 SAN 24 ! 28 SAN 28 ! 30 SAN 30 ! 12 SAN 12

33 SAN 33 ! 8 SAN 8 ! 32 SAN 32 ! 4 SAN 4 ! 47 B SAN 8 ! 43 B SAN 4 ! 48 B SAN 9

51 B SAN 1 ! 52 B SAN 1 ! 54 B SAN 1 ! 55 B SAN 1 ! 57 B SAN 1 ! 58 B SAN 1 ! 59 B SAN 2

60 B SAN 2 ! 40 B SAN 1 ! 42 B SAN 3 ! 45 B SAN 6 ! 49 B SAN 1 ! 53 B SAN 1 ! 56 B SAN 1

63 B SAN 2 !

1777666622 13331322333 22313 3 444555555564444556

892601345672657906791595148123648023824738124578900259363

13 Iflo ga 3-2---4-2--2-- 000000

4 Cype rus -23-444-- 000001

11 Molt ik -342444--2-------2-------------------------------------- 000001

21 Rume x 2-- 000001

29 Lotu s 434-432---2--- 000001

34 Gyna ndr   ------2-- 000001

42 Caki le   -22-------2--- 000001

43 Lapp ula   -22--3--- 000001

44 Cres sa   -2--- 000001

45 Cale ndul 33-- 000001

12 Arne b d. 22--------22--- 000010

27 Picr is   442------24-- 000010

28 Sene cio   432-2-32-24-- 000010

31 Card uus   4-2-------3-- 000010

14 .... .   ---------2--- 000011

18 Astr ag c 43---2--234----------2----------------------------------- 000011

26 Rhan teri -2------44-- 000011

32 Koel pin   ----------2-- 000011

33 Rese da   --2----2-32-- 000011

35 Bras sica 32--2232434-- 000011

36 Trig onel ---------2-- 000011

37 Sals ola   -------422--- 000011

39 Savi gnya 2---------3-- 000011

22 Malv a   2-2----------------2------------------------------------- 000100

6 Lyci um   -------------2--- 000101

8 Astr ag a -------2---222--- 000101

9 Laun a c. ------------3--22-- 000101

16 Alli um   ----------2-3-- 000101

20 Emex   -------------------2------------------------------------- 000101

46 Thre isaa -----------2--- 000101

10 Laun a m. ----------------------------------22--------------------- 00011

17 Astr ag s ---------------------------------2----------------------- 00011

7 Plan tago 442-444243433242323232--------------4-------------------- 001

24 Schi sm 2-3-2-42443232424322-2--------2-----32------------------- 001

2 Heli an -------------224242222-2324343433324-42------------------ 01

3 Stip a -23-24---3-------234-422444--------3--22----------------- 01

5 Fago nia --------3-2----------22----2222----2-2------------------- 01

23 Neur ad 22--2-2-442--------2-------22-------2-------------------- 01

1 Halo x -------------------------------------4333344343432222222 1

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0011111   011111   011110000111

01111   01111

Appendix 2 Check list of encountered birds in the studied areas

N	Species	Scientific name	Status	SAANR	B-SAANR	Kabd	R-Kabd	Pivot
1	mallard	*Anas platyrhynchos*		✓				
2	little grebe	*Tachybaptus ruficollis*		✓				
3	european white stork	*Ciconia ciconia*	Rare/ Accidental					✓
4	glossy ibis	*Plegadis falcinellus*						✓
5	little bittern	*Ixobrychus minutus*						✓
6	squacco heron	*Ardeola ralloides*		✓				✓
7	cattle egret	*Bubulcus ibis*		✓				✓
8	grey heron	*Ardea cinerea*		✓				✓
9	great egret	*Ardea alba*						✓
10	little egret	*Egretta garzetta*		✓				✓
11	great cormorant	*Phalacrocorax carbo*						✓
12	lesser kestrel	*Falco naumanni*	Vulnerable	✓				
13	common kestrel	*Falco tinnunculus*		✓		✓		✓
14	eurasian hobby	*Falco subbuteo*						✓
15	black kite	*Milvus migrans*		✓				✓
16	western marsh harrier	*Circus aeruginosus*		✓		✓		✓
17	northern harrier/hen harrier	*Circus cyaneus*	Rare/ Accidental	✓				✓
18	pallid harrier	*Circus macrourus*	Near-threatened	✓				✓
19	montagu's harrier	*Circus pygargus*		✓				✓
20	eurasian buzzard	*Buteo buteo*		✓		✓		✓
21	long-legged buzzard	*Buteo rufinus*		✓		✓		✓
22	greater spotted eagle	*Aquila clanga*	Vulnerable	✓				✓
23	steppe eagle	*Aquila nipalensis*		✓		✓		✓
24	eastern imperial eagle	*Aquila heliaca*	Vulnerable					✓
25	corncrake	*Crex crex*	Near-threatened	✓				
26	common moorhen	*Gallinula chloropus*						✓
27	northern lapwing	*Vanellus vanellus*						✓
28	red-wattled lapwing	*Vanellus indicus*						✓
29	white-tailed plover	*Vanellus leucurus*		✓				✓
30	eurasian curlew	*Numenius arquata*	Near-threatened					✓
31	common sandpiper	*Actitis hypoleucos*		✓				✓
32	little stint	*Calidris minuta*		✓				
33	ruff	*Philomachus pugnax*		✓				✓
34	black-winged pratincole	*Glareola nordmanni*	Near-threatened					✓
35	rock dove	*Columba livia*						✓
36	woodpigeon	*Columba palumbus*		✓				✓

37	european turtle dove	*Streptopelia turtur*		✓		✓		✓
38	eurasian collared dove	*Streptopelia decaocto*		✓		✓		✓
39	laughing dove	*Streptopelia senegalensis*		✓		✓		✓
40	namaqua dove	*Oena capensis*		✓				✓
41	common cuckoo	*Cuculus canorus*		✓				✓
42	common swift	*Apus apus*		✓		✓		✓
43	european roller	*Coracias garrulus*	Near-threatened	✓		✓		✓
44	european bee-eater	*Merops apiaster*		✓		✓		✓
45	common hoopoe	*Upupa epops*		✓		✓		✓
46	red-backed shrike	*Lanius collurio*		✓		✓		✓
47	isabelline shrike	*Lanius isabellinus*		✓		✓		✓
48	southern grey shrike	*Lanius meridionalis*		✓		✓		✓
49	woodchat shrike	*Lanius senator*		✓		✓		✓
50	masked shrike	*Lanius nubicus*		✓		✓		✓
51	barn swallow	*Hirundo rustica*		✓		✓		
52	red-rumped swallow	*Cecropis daurica*		✓		✓		✓
53	greater hoopoe-lark	*Alaemon alaudipes*		✓				
54	bar-tailed lark	*Ammomanes cinctura*		✓		✓		
55	greater short-toed lark	*Calandrella brachydactyla*		✓		✓	✓	
56	lesser short-toed lark	*Calandrella rufescens*		✓			✓	
57	dunn's lark	*Eremalauda dunni*				✓		
58	crested lark	*Galerida cristata*		✓	✓	✓	✓	✓
59	eurasian skylark	*Alauda arvensis*		✓		✓	✓	✓
60	black-crowned sparrow-lark	*Eremopterix nigriceps*		✓		✓	✓	✓
61	great reed warbler	*Acrocephalus arundinaceus*		✓				✓
62	common chiffchaff	*Phylloscopus collybita*		✓				✓
63	greenish warbler	*Phylloscopus trochiloides*	Rare/ Accidental	✓		✓		✓
64	blackcap	*Sylvia atricapilla*		✓				✓
65	desert warbler	*Sylvia nana*		✓		✓		✓
66	ménétriés's warbler	*Sylvia mystacea*		✓				✓
67	european starling	*Sturnus vulgaris*						✓
68	song thrush	*Turdus philomelos*		✓				✓
69	common nightingale	*Luscinia megarhynchos*		✓				✓
70	common redstart	*Phoenicurus phoenicurus*		✓		✓		
71	common stonechat	*Saxicola torquatus*		✓		✓		✓
72	isabelline wheatear	*Oenanthe isabellina*		✓	✓	✓	✓	
73	northern wheatear	*Oenanthe oenanthe*		✓	✓	✓		✓
74	pied wheatear	*Oenanthe pleschanka*		✓				
75	black-eared wheatear	*Oenanthe hispanica*		✓		✓		✓

76	desert wheatear	*Oenanthe deserti*		✓	✓	✓	✓	✓
77	spotted flycatcher	*Muscicapa striata*		✓		✓		
78	red-breasted flycatcher	*Ficedula parva*		✓		✓		
79	house sparrow	*Passer domesticus*		✓	✓	✓	✓	✓
80	spanish sparrow	*Passer hispaniolensis*		✓		✓		✓
81	yellow wagtail	*Motacilla flava*		✓		✓		✓
82	grey wagtail	*Motacilla cinerea*		✓		✓	✓	✓
83	white wagtail	*Motacilla alba*		✓		✓		✓
84	tawny pipit	*Anthus campestris*		✓		✓		✓
85	red-throated pipit	*Anthus cervinus*		✓		✓		✓
86	water pipit	*Anthus spinoletta*		✓				✓
87	corn bunting	*Emberiza calandra*		✓		✓	✓	✓
88	cinereous bunting	*Emberiza cineracea*	Near-threatened	✓				
89	ortolan bunting	*Emberiza hortulana*		✓		✓	✓	✓

Appendix 3 Avifauna species recorded during 2009

Common name	Scientific name	Winter	Spring	Summer	Fall
little grebe	*Tachybaptus ruficollis*	x	x	x	
garganey	*Anas querquedula*			x	x
littel bittern	*Ixobrychus minutes*	x	x		
squacco heron	*Ardeola ralloides*		x		
cattle egret	*Bubulcus ibis*		x		
little egret	*Egretta garzetta*				x
grey heron	*Ardea cinerea*		x		x
purple heron	*Ardea purpurea*		x		x
honey buzzard	*Pernis apivorus*		x		x
black kite	*Milvus migrans*	x	x		
egyptian vulture	*Neophron percnopterus*		x		x
black vulture	*Aegypius monachus*		x		
short-toed eagle	*Circaetus gallicus*		x		
marsh harrier	*Circus aeruginosus*		x		x
pallid harrier	*Circus macrourus*		x		x
montagu's harrier	*Circus pygargus*		x		x
sparrowhawk	*Accipiter nisus*		x		x
common buzzard	*Buteo b. vulpinus*				x
long-legged buzzard	*Buteo rufinus*	x			
greater spotted eagle	*Aquila clanga*	x			
steppe eagle	*Aquila nipalensis*		x		
booted eagle	*Hieraaetus pennatus*		x		x
bonelli's eagle	*Hieraaetus fasciatus*	x	x		
osprey	*Pandion haliaetus*	x	x		x
lesser kestrel	*Falco naumanni*		x		
common kestrel	*Falco tinnunculus*		x		
eurasian hobby	*Falco subbuteo*				x
spotted crake	*Porzana porzana*		x		
little stint	*Calidris minuta*		x		
common snipe	*Gallinago gallinago*				x
common sandpiper	*Actitis hypoleucos*		x		
slender-billed gull	*Larus genei*		x		

littel tern	*Sterna albifrons*		x	x	
common wood pigeon	*Columba palumbus*		x		
collared dove	*Streptopelia decaocto*		x	x	x
turtle dove	*Streptopelia turtur*		x		x
palm/laughing dove	*Streptopelia senegalensis*		x	x	x
namaqua dove	*Oena capensis*		x		x
common cuckoo	*Cuculus canorus*		x		x
barn owl	*Tyto alba*		x		
european scops owl	*Otus scops*		x		x
nithtjar	*Caprimulgus europaeus*		x		
common kingfisher	*Alcedo atthis*	x			x
pied kingfisher	*Ceryle rudis*	x			
european bee-eater	*Merops apiaster*		x		x
roller	*Coracias garrulus*		x		
hoopoe	*Upupa epops*		x		x
desert lark	*Ammomanes deserti*		x		x
greater hoopoe lark	*Alaemon alaudipes*		x	x	x
greater short-toed lark	*Calandrella brachydactyla*		x		x
crested lark	*Galerida cristata*		x	x	x
sand martin	*Riparia riparia*		x		
swallow	*Hirundo rustica*		x		
red-rumped swallow	*Hirundo daurica*		x		
red-throated pipit	*Anthus cervinus*		x		
yellow wagtail	*Motacilla flava*		x		
rufous bush robin [chat]	*Cercotrichas galactotes*		x		
white-throated robin	*Irania gutturalis*		x		
redstart	*Phoenicurus phoenicurus*		x		x
whinchat	*Saxicola rubetra*		x		
isabelline wheatear	*Oenanthe isabellina*		x		
black-eared wheatear	*Oenanthe hispanica*		x		
desert wheatear	*Oenanthe deserti*		x		
cetti's warbler	*Cettia cetti*		x		x
sedge warbler	*Acrocephalus schoenobaenus*		x		x
graceful warbler	*Prinia gracilis*		x	x	x
marsh warbler	*Acrocephalus palustris*		x		

great reed warbler	*Acrocephalus arundinaceus*		x		x
desert warbler	*Sylvia nana*	x	x		
eastern orphean warbler	*Sylvia hortensis*		x		x
barred warbler	*Sylvia nisoria*		x		x
lesser whitethroat	*Sylvia curruca*		x		x
common whitethroat	*Sylvia communis*		x		x
garden warbler	*Sylvia borin*		x		x
blackcap	*Sylvia atricapilla*		x		
common chiffchaff	*Phylloscopus collybita*		x		x
spotted flycatcher	*Muscicapa striata*		x		x
golden oriole	*Oriolus oriolus*		x		x
isabelline shrike	*Lanius isabellinus*	x	x		x
red-backed shrike	*Lanius collurio*		x		
lesser grey shrike	*Lanius minor*		x		
southern grey shrike	*Lanius excubitor*	x	x		x
woodchat shrike	*Lanius senator*		x		
masked shrike	*Lanius nubicus*		x		
house sparrow	*Passer domesticus*	x	x	x	x
spanish sparrow	*Passer hispaniolensis*	x	x		
pale rock sparrow	*Petronia brachydactyla*		x		
chestnut-shouldered/ yellow-throated sparrow	*Petronia xanthocollis*		x		
ortolan bunting	*Emberiza hortulana*		X		

Appendix 4 Predator and prey species

Predators (seen predating or trying)	Prey (seen as victims)
cattle egret *Bubulcus ibis*	hoopoe *Upupa epops*
squacco heron *Ardeola ralloides*	crested lark *Galerida cristata*
steppe eagle *Aquila nipalensis*	barn swallow *Hirundo rustica*
booted eagle *Hieraaetus pennatus*	chiffchaff *Phylloscopus collybita*
short toed eagle *Circaetus gallicus*	garden warbler *Sylvia borin*
sparrow hawk *Accipiter nisus*	black cap warbler *Sylvia atricapilla*
steppe buzzard *Buteo buteo vulpinus*	marsh warbler *Acrocephalus palustris*
marsh harrier *Circus aeruginosus*	red throat pipit *Anthus cervinus*
common kestrel *Falco tinnunculus*	yellow wagtail *Motacilla flava*
red-backed shrike *Lanius collurio*	ortolan bunting *Emberiza hortulana*
wood chat shrike *Lanius senator*	house sparrow *Passer domesticus*
desert monitor *Varanus griseus*	libyan jird *Meriones libycu*
red fox *Vulpes vulpes*	long eared hedgehog *Hemiechinus auritu*

Appendix 5 Additional observations on the distribution and behaviour of larks

1- Greater hoopoe larks

Greater hoopoe larks were generally encountered as solitary individual inhabiting open lands with sparse vegetation cover, especially sandy shrubby and grassy habitats dominant with *Stipa* grass and/or *Haloxylon* shrubs in SAANR. *Haloxylon* community as was seen in chapter 2 (Vegetation cover), formed the favourable habitat for hooope larks during the breeding season until mid-summer. All studied areas were vacant of greater hoopoe larks throughout winter and summer during 2008 and 2009, except SAANR. In spite of dense vegetation cover in the coastal area of SAANR, greater hoopoe larks were not found in this habitat. Also, they were not seen in ridge areas with any substantial topography. Over the ten months of survey, they were found in the same habitats with little shift, which means they are permanently resident in this protected area SAANR throughout the year. The B-SAANR area was devoid of greater hoopoe larks in winter and summer (Figure 3.9 and 3.10). Absence of greater hoopoe larks and most other larks as well and very low density of crested larks were correlated with poor vegetation cover and plant species diversity (Chapter 2).

Until mid summer (June), two greater hoopoe larks were found inhabiting their specific territories. In July and August, only one male was in his territory, but he was not seen later on during September and early October. In August, September and October greater hoopoe larks were not seen any more in their previous territories during early or late morning. They quitted their territories when they became unsuitable for foraging. Two territories were deserted almost one month earlier than the rest. As the breeding season ceased, greater hoopoe larks became progressively less territorial.

2- Crested larks

The abundance of crested larks was associated with open grass habitats. They preferred to forage in sparse vegetation cover vary from 10-40 cm where ground insect, arthropods and seeds were available. In the protected areas SAANR and Kabd, *Stipa* and *Stipocyprus* communities were the most favourable habitats to crested larks, while barley and trefoil crops (especially adjacent to fertilizer) in agricultural habitats, the Pivot farm, attracted crested larks.

In the Pivot, crested larks avoided maize crops and other tall and dense crops when it became >70cm as well as hedge. However, they shaded under trees in summer particularly around waterholes that extremely remarkable in Talha waterhole in SAANR.

Crested larks were territorial during the breeding season but gregarious during autumn and summer. They foraged in groups 3-11 individuals and shaded in groups of 40-65 individuals during summer. Crested larks were sparse in winter and aggregated in summer around the Talha water hole in SAANR. In the Pivot, crested larks foraged around arable crops in winter and within arable crops in summer to avoid solar heat.

3- Skylarks

Skylarks were found in SAANR, Kabd and the Pivot farm. Their habitat preference was similar to crested larks. They were gregarious, foraged in large flock sizes of 30-45 individuals during autumn and winter. Skylarks migrated directly as the spring season started. No signs of breeding were seen for skylarks during this study. Absence of skylark pairs or partners supports previous noting of it being a non-breeding species in Kuwait for several decades (Gregory, 2005).

4- Black-crown sparrow larks

In the non-breeding season, black-crown sparrow larks were observed foraging in small groups 3-7 individuals. But, in early and late breeding season, several records were of two females accompanying a male. This could mean that this species is polygamous, but this needs further investigations.

In summer, black-head finch larks were found perching on vertical water dripping plastic pipes (1.5m height). These pipes were spaced 3m and the top of each pipe can hold only one passerine individual. Hence, it was not clear if they preferred to be spaced naturally or enforced to do that. They spend long periods during the middle of the day on these pipes even if there were no water drops, and may have chosen this microclimate to be somewhat far from ground heat radiation.

5- Bar-tailed larks

Bar-tailed larks occurred in SAANR and Kabd, inhabiting ridges with deep slopes. All observation records for bar-tailed larks were one or two individuals. Bar-tailed larks where seen as pairs in the breeding season. Bar-tailed larks were not seen at all drinking or shading near Talha and Kabd waterholes.

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