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The decline of the Djibouti francolin and juniper woodland in the Forêt du Day, Djibouti: A response to climate changes and grazing pressure?

By

Zomo Sikander Yusuf Fisher

A report submitted in partial fulfilment of the requirements for the MSc and/or the DIC.

September 2007

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ABSTRACT

The Forêt du Day in the Goda Massif in Djibouti is the stronghold of the Critically Endangered Djibouti francolin *Francolinus ochropectus*, a ground-dwelling bird of the Order Galliformes that has declined by >90% in the last 20 - 30 years. The francolin has been traditionally associated with *Juniperus procera*, which was once the dominant tree of the Forêt du Day but which has also declined markedly. In east Africa and the Arabian Peninsula other juniper forests have also declined, probably due to climatic changes, felling, and intensive pastoralism. The reasons for the decline of the Djibouti francolin and the juniper forest are poorly understood. This study provides the first quantitative assessment of the vegetation and health of the forest, an estimate of the francolin's population, an assessment of the variables that correlate with its presence, and a study of the anthropogenic uses of the forest ecosystem.

The forest was systematically sampled using quadrats on a grid system, collecting quantitative information on plant community composition, juniper health, grazing intensity and environmental variables. Transects were used to document francolin presence. Interviews were conducted in 5 villages to obtain information about forest usage, francolin sightings and the capacity of villagers for community-based conservation. Biological, environmental and social data were overlaid in a GIS. Generalized linear modelling was used to determine predictors of juniper condition and francolin presence, and correlations were made between social and empirical data.

The remaining juniper forest in the Forêt du Day is in poor condition. Although junipers are significantly healthier at higher altitudes even the healthiest forest is 50% dead. As with other juniper forests in the region, climate change is probably the main cause of decline. However, grazing pressure has a significant interaction with altitude and is likely to be exacerbating the effects of climate change.

The estimated francolin population is 382 – 1179 individuals. Francolins are more abundant where tree cover is high. This cover now mostly consists of *Buxus hildebrandtii*, which appears to have mostly replaced the original juniper. In areas of high tree cover grazing intensity is significantly negatively correlated with francolin presence.

Anthropogenic influences on juniper health and francolin decline are mediated through the large number of cows grazing in the forest. Tree felling and hunting are of minimal concern. Villagers are concerned by drought, from which their livestock have suffered. A conservation action plan has been proposed that aims to incorporate the livelihoods of villagers and protection of the Forêt du Day.

The Forêt du Day ecosystem requires urgent international attention and formal national protection. Community participation is essential for any conservation programme. Future research should survey other francolin populations in Djibouti and monitor the francolin population using this study as a baseline.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

1.1 The problem with birds and forests

Seventy-six percent of the world's threatened birds inhabit forests (IUCN, 2006). Africa holds 12% of all threatened birds, mostly in tropical and subtropical forests; of the 1,230 Important Bird Areas in Africa and its associated islands, almost exactly half contain forest habitat (P. McGowan, pers. comm.). What threats particularly affect forest birds? Most evidence points to forest fragmentation (Turner, 1996, Beier et al., 2002), which restricts and destroys suitable habitat, but subsistence forest use, pastoralism and grazing can also negatively affect bird populations (Jansen et al., 1999, Fuller, 1995). Forests equally rely on birds for survival, through services such as fruit and seed dispersal (Cordeiro and Howe, 2001, Redford, 1992).

Global climate change is one of the biggest threats to forests (Parry et al., 2007), and long-lived trees are poorly equipped to deal with rapidly changing climatic patterns. In this study, I present the case of the Critically Endangered Djibouti francolin *Francolinus ochropectus*, endemic to a small patch of forest in the central Djiboutian mountains, and the dying juniper forest in which it resides. Evidence for a link between the dying juniper forest and the declining francolin population will be investigated and the best predictors for francolin presence and juniper health will be evaluated. The possibility for community-based conservation will also be assessed.

1.1.1 *Declining juniper forests in Africa and Asia*

The global status of juniper woodlands is a cause of concern. Large declines have been observed in juniper forests in parts of Europe and the Americas (Diamond et al., 1995, Clifton et al., 1997, Gauquelin et al., 1999, Munoz-Reinoso, 2004, Garcia et al., 1999), attributed to climatic changes such as drought, human disturbance, habitat loss and degradation, changes in land use management, acid rain, extraction and agricultural encroachment. Junipers are slow-growing, which can exacerbate recovery problems. Of the 52 recognised species of juniper, 12 (23%) are on the IUCN Red List (IUCN, 2006). The only species of *Juniperus* in sub-Saharan Africa is *Juniperus procera*. Woodlands of this species are of particular concern due to factors threatening their ecosystems that are associated with development in developing countries.

Increasing human population associated with intensive pastoralism and illegal logging are blamed for the deteriorating juniper woodlands in Baluchistan, Pakistan (Ahmed et al., 1990b). As a result of the juniper forest death, extensive soil erosion has threatened the agricultural systems that originally displaced the juniper woodland. Mistletoe often takes hold of stressed junipers, increasing their rate of death (Ahmed et al., 1990a). In Saudi Arabia, *Juniperus procera* and *Juniperus phoenicea* woodlands in the western highlands are declining dramatically in areas of low altitude (Asmodé, 1989), and in the Asir highlands, *J. procera* woodlands have exhibited a widespread decline with extensive tree death below 2400 m (Blot, 1994, Fisher, 1997). Hypotheses proposed for the decline include temperature-induced dieback, periodic droughts and a long-term increase in aridity and overgrazing. A similar situation is occurring in the montane juniper woodlands of Oman, where healthy stands of *Juniperus excelsa* subsp. *polycarpos* are now restricted to altitudes above 2400 m, below which most trees are dead or dying (Gardner and Fisher, 1996). In this example, grazing and extraction of wood play a minimal role, but water stress has been partially blamed for the decline: Junipers inhabiting wadis are significantly healthier than those distant from wadis. Hydrology is thus thought to have a role in the health of juniper woodlands (Fisher and Gardner, 1995).

Across the Red Sea in east Africa, Borghesio et al. (2004) describe two severely degraded *Juniperus procera* forests in the South Ethiopian Endemic Bird Area. *J. procera* is commercially very important in Ethiopia (Bekele et al., 1993). One forest, Mankubasa, has been targeted for strong commercial exploitation of fuel wood and timber, while another forest, Arero, is at threat mainly from seasonal use by pastoral nomadic people and wildfires. The lack of good roads in Arero has spared the forest from commercial exploitation and subsistence use by villagers is the main cause of the decline. In 16 years, the forests have decreased by 10 – 40 %.

While climatic effects are largely attributed to forest decline on the Arabian Peninsula, overgrazing, inhibiting recruitment, is seen as the main threat to the Arero juniper woodland in Ethiopia. Similar examples are noticeable in isolated parts of the western Mediterranean, where thuriferous juniper woodlands are at risk from overgrazing (Gauquelin et al., 1999). Subsistence wood extraction for firewood is also thought to be an important factor in juniper forest declines in southwest Asia and east Africa, but commercial logging is less common. Climatic effects in general may be driving juniper forest dieback, but in different areas, such as those described here, death may be exacerbated by factors such as unsustainable wood-use and grazing.

1.1.2 *The threats facing Galliformes in forests*

The vast majority of Galliformes (gamebirds) are ground-dwelling and many of these live in forests (Fuller et al., 2000). Of the 284 recognised species of Galliformes, 72 (one quarter) are on the IUCN Red List. A further 36 species (13%) are Near Threatened (IUCN, 2006). Almost all Galliformes have traditionally faced persecution through hunting because of the high protein content of their meat and eggs, and their ease of capture (Fuller et al., 2000), but hunting is just one of the threats facing this highly threatened group.

Most of the declines in Galliformes is attributed to habitat destruction, caused by deforestation (del Hoyo et al., 1994), forest clearance for agriculture (Javed et al., 1999), and urban development (Dai et al., 1998). Forest fragmentation in particular can isolate populations of terrestrial birds, unable to fly long distances between fragments (Laurance et al., 1998). Small isolated populations can suffer from inbreeding depression, genetic drift and are less resistant to shocks such as drought (Stephens et al., 2004, Keller and Waller, 2002, Laurance and Williamson, 2001).

Habitat degradation, on the other hand, is more gradual than direct habitat destruction, with its effects on terrestrial avifauna accumulating over time. This is often the case in woodlands and forests used by subsistence communities, where selective logging practices are carried out and grazing is a major form of disturbance (Ayyad, 2003). Intensive pastoralism is seen as a major contributing factor to the declines in birds such as Nahan's francolin *Francolinus nahani*, a strict tropical rainforest specialist in the highly degraded Mabira forest in eastern Uganda and the Democratic Republic of Congo (Fuller et al., 2000, Dranzoa, 1998). Other types of human disturbance can threaten ground-dwelling birds, such as collection of bamboo in the Sichuan, China, thought to negatively affect the Sichuan hill-partridge (Dai et al., 1998). However, other species are regularly found in secondary and degraded habitats (e.g. the orange-necked hill-partridge *Arborophila davidi* in southern Vietnam) and are apparently able to tolerate appreciable amounts of disturbance (Fuller et al., 2000, Atkins and Tentij, 1999, Lawes et al., 2006).

Generalist species tend to do better than specialists where habitat loss and degradation is concerned, whereas long generation time and large body size particularly put birds at risk of persecution (Owens and Bennet, 2000). Galliformes living in habitats with higher habitat diversity are at a significantly lower risk than those that are more specialised (Keane, 2005), and thus forest degradation and fragmentation are a cause of immediate concern for many forest specialists around the world. The Djibouti francolin, one of 41 species in the genus

Francolinus, is thought to be a specialist, found only in an area of c. 15 km^2 in the mountains of Djibouti (Fuller et al., 2000).

1.2 The Forêt du Day ecosystem

The Forêt du Day (the Day Forest, Figure 1) is a dry tropical Afromontane mixed woodland (White, 1983) in the Goda Massif mountain range in the Republic of Djibouti (Figures 2 and 3). The Forêt du Day (11º 46' N, 42º 39' E) occupies an area of c. 15 km^2 with an altitudinal range between c. 1200 m to c. 1750 m and is a BirdLife Endemic Bird Area. The dominant forest tree was formerly the African pencil cedar, *Juniperus procera*, which formed a closed canopy forest until a dramatic decline in last 20 – 30 years left a large proportion of the junipers dead and dying, and the canopy open (Blot, 1986, Blot, 1994, Bealey et al., 2006). These recent events have sparked concern from both Djiboutian governmental ministries and foreign non-governmental organisations.

Figure 1 Photo showing dead junipers, taken in the Garab plateau in the Forêt du Day. Photo © Zomo S Y Fisher 2007.

Of particular concern are the forest's associated fauna, notably the Critically Endangered Djibouti francolin (BirdLife International, 2004), which is a main focus of this report. The forest is home to many other rare species, some of which are endemic to the horn of Africa such as the Klipspringer, *Oreotragus oreotragus somalicus* (Antelope Specialist Group, 1996) and Hamadryas baboon, *Papio hamadryas* (Primate Specialist Group, 1996). The African leopard, *Panthera pardus pardus* has also been reported in the Forêt du Day (Künzel et al., 2000). A similar forest characterized by *J. procera* exists in Djibouti in the Mabla Mountains, 80 km to the north-east, but its status is currently unknown.

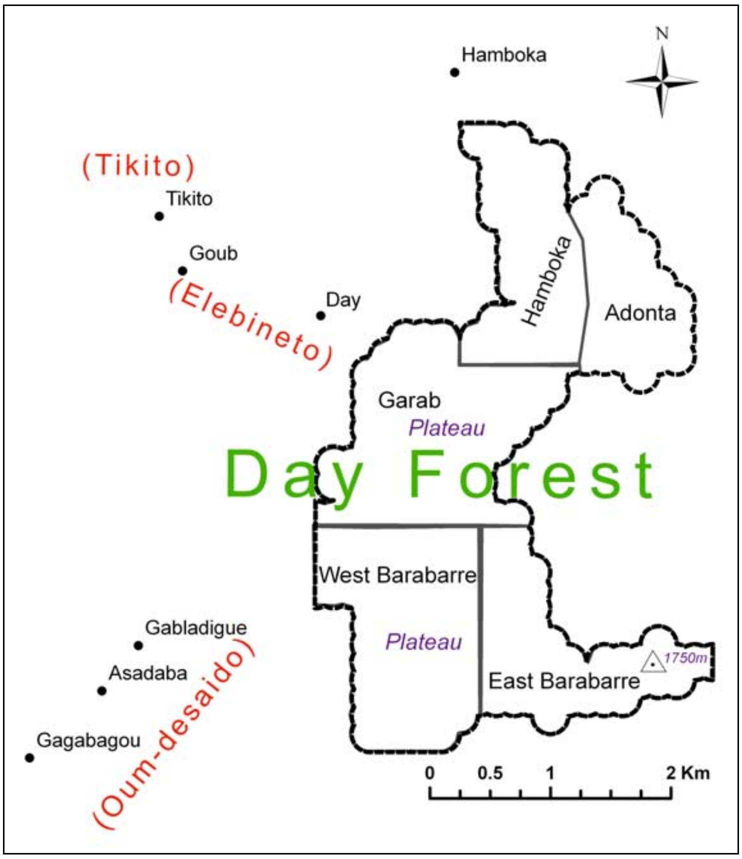

Figure 2 Outline map of the province of Day. The dashed black outline signifies the edge of the study site (the extent of the juniper forest). Black dots show the location of villages, and the names of the tribes that the villages belong to are shown in red. The 5 main regions in the forest are shown.

Continuous meteorological data has not been collected for the Day region, but the climate of the Forêt du Day is typically mild with frequent rain episodes in the wet season (October to May), and hot and humid with sporadic rainfall in the dry season (June to September) (USAID, 2007a). Mist and fog often engulf the higher altitudes. The strong, hot and dusty 'khamsin' wind blowing out from Libya and Egypt typically dominates for about 50 days between June and August. In recent years, the climate of the Forêt du Day has been unpredictable: There have been frequent occurrences of droughts in the last 10 years, which have been becoming increasingly common in the last 4 years. Rain only recently returned to the area in 2006 after 5 seasons of consecutive drought. However, there are new concerns that the rains in 2007 will fail, as they are currently overdue (USAID, 2007a).

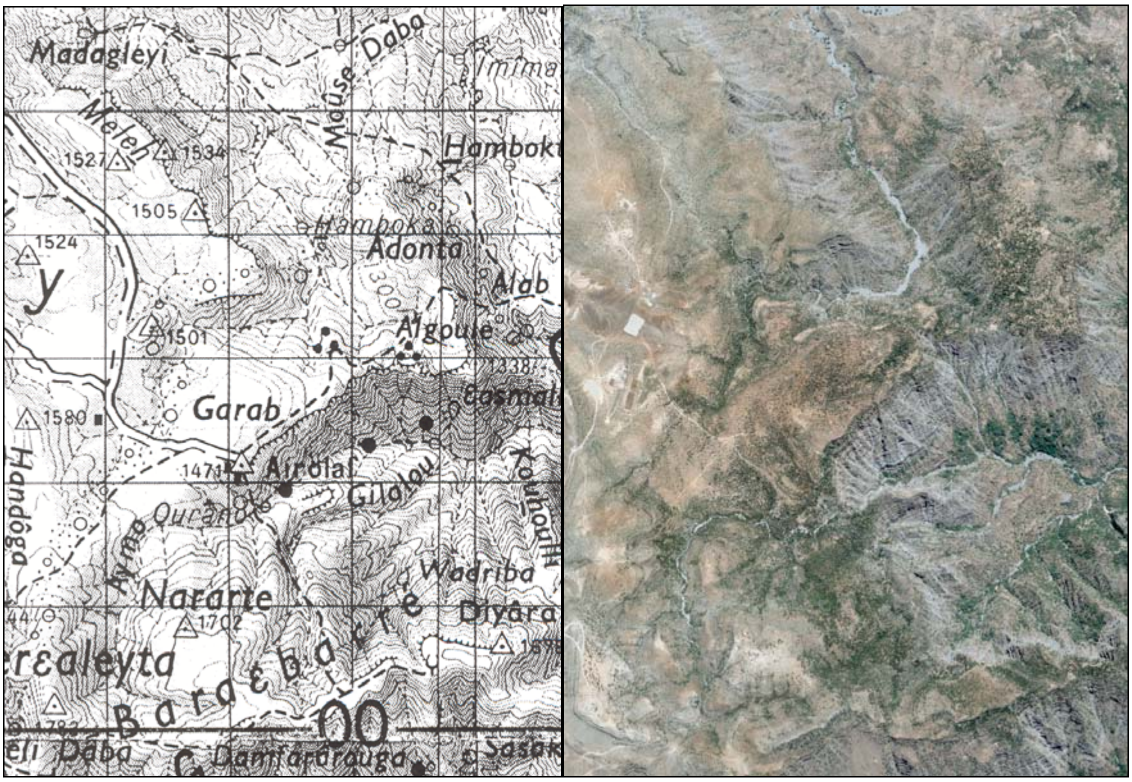

Figure 3 Contour map and recent satellite image of the Forêt du Day. Grid squares on contour map represent square kilometres. Map and image in WGS84 and UTM projection, permission obtained from the Ministère de l'Habitat, de l'Urbanisme, de l'Environnement et de l'Aménagement du Territoire, Djibouti. Map and satellite image are in the same scale of reference. Image in 2 feet per pixel resolution, purchased from MapMart Inc., date of acquisition: 05.06.2006.

1.2.1 *The Juniperus procera forest*

Juniperus procera Hochst. ex Endl. (Figure 4) is one of 52 species in the genus *Juniperus* of the family Cuppressaceae (Farjon, 2005). Its distribution is predominantly in the mountainous regions and highlands of east Africa and also in the mountains adjoining the Red Sea in Saudi Arabia and Yemen. Its altitudinal range in Africa is between 1300 and 3000 m but it is most commonly found between 1800 and 2700 m. Its distribution is limited by rainfall, and it is most luxuriant where annual precipitation averages 1000 - 1200 mm. However, stunted trees can be found in savannah areas with as low as 400 mm annual precipitation. The dry season is at least 5 months in areas of *J. procera* woodland (Farjon, 1992).

The IUCN Red List classifies *J. procera* as Lower Risk/Near Threatened, with the major threats listed as human-induced habitat loss or degradation due to wood plantations and selective logging, and changes in native species dynamics (World Conservation Monitoring Centre, 1998).

Figure 4 Photo of healthy *Juniperus procera*. Photo © Zomo S Y Fisher 2007.

In Djibouti, *J. procera* in the Forêt du Day coexists with two other common tree species, African olive, *Olea europaea* subsp. *africana* and Box, *Buxus hildebrandtii*, forming a mixed woodland. Its range is at the lower end of altitudes when compared against its global distribution, with the highest peak in the Goda Mountains being c. 1750 m (Audru et al., 1994). Selective logging may have been carried out in the past but is not considered to be the main cause of its current decline, rather high grazing pressure (Blot, 1987), short- or long-term climatic changes, acid rain and fungal disease (Magin, 2001) are proposed as contributors to the forest's death. There is a lack of research on *J. procera* in the horn of Africa, and no recent published work on the Forêt du Day. Consequently, little is known or understood regarding its threatened status.

1.2.2 *The Djibouti francolin*

The Djibouti francolin, *Francolinus ochropectcus* Dorst and Jouanin (Figure 5), first described in 1952 (Mayr, 1957, Dorst and Jouanin, 1952) is Critically Endangered (BirdLife International, 2004) and is endemic to the juniper forests of Djibouti. Its major threats are listed as habitat degradation due to subsistence firewood extraction and encroachment of small holder farming, hunting and changes in native species dynamics (BirdLife International, 2004, BirdLife International, 2000, Magin, 2001). The precise nature of these threats are unknown and undocumented. The Djibouti francolin has had a rapid decline in the last 20 years, which is thought to have exceeded 90% (Fuller et al., 2000).

Figure 5 Photo of *Francolinus ochropectus*. Photo © Samantha Cartwright 2007.

The species' stronghold is considered to be in the Forêt du Day, where the amount of suitable habitat is an estimated 14 – 15 km^2 (Fuller et al., 2000). The species is also occurs in the Mabla Mountains, 80 km to the north-east, where it was first recorded in 1985, but its current population or status in Mabla is unknown (Bealey et al., 2006). The Forêt du Day is thought to contain the only viable population (BirdLife International, 2007) as at Mabla there has been significant human disturbance in the remaining forest stands, heavily exploited for firewood and grazing (Magin, 2001).

Between 1977 and 1983, habitat available to the francolin in the Forêt du Day was halved (McGowan, 1994), with a corresponding population decline from 5,600 to 1,500 birds between 1978 and 1985 (McGowan, 1995). In 1998, the population of *F. ochropectus* was estimated between 500 and 1000 birds (Welch and Welch, 1998) and a recent survey has estimated that the population is 600 - 750 individuals (Bealey et al., 2006).

Little is known about the ecology of the Djibouti francolin, but its breeding season is thought to be between December and January (McGowan, 1994, Blot, 1985) with an estimated clutch size of 5 - 7. To date, only one nest has been recorded (Madge and McGowan, 2002). Its diet is thought to include termites, insects and seeds and fruits of box and juniper trees and euphorbias (Blot, 1985). A shy and elusive bird historically associated with the juniper forest, it also occurs in secondary and possibly degraded woodland, and in small clusters in patches of dense vegetation (Madge and McGowan, 2002). A recent study observed that the francolin may be occupying a marginal habitat around the periphery of the remaining closed woodland, with many birds seen in open woodland and wadis. Francolins appeared to be avoiding large dead junipers and possibly finding forage from species such as *Ficus* in open woodland areas (Bealey et al., 2006). The evidence is, however, inconclusive.

1.3 Social context and policy areas

1.3.1 *Demographics of the province of Day*

The province of Day falls in the south-eastern part of the Afar region, which is shared between Djibouti, Ethiopia and Eritrea. Afar people were typically nomadic, following a lifestyle dominated by pastoralism, but in Djibouti true nomads are now rare and most Afar are sedentary, only occasionally showing nomadic behaviour (H. Rayaleh, Ministry for the Environment, Djibouti, pers. comm.). The vast majority of Afar are Muslims and speak Afar, a language belonging to the East Cushitic family of languages spoken in the horn of Africa (Bliese, 1976).

As a reaction to the lack of Afar presence in the government, in 1991 civil war broke out in Djibouti between an Afar rebel group and the predominantly Somali government (Kadamy, 1996). The Djiboutian Civil War ended in December 1994, during which time significant felling of trees (H. Rayaleh, Ministry for the Environment, Djibouti, pers. comm.) and army manoeuvres (Magin, 2001) occurred in the Forêt du Day.

The province of Day is a region of approximately 45 km^2, in the highest altitudes of the Goda Massif mountain range in Djibouti that includes the Forêt du Day and 9 villages (A. Dabaleh, chief of the province of Day, pers. comm.). It is split into five local clans, Elebineto, Tikito, Hamoda, Garoda and Oum-desaido. The villages in the province of Day vary in size, between 6 and 80 households. No villages occur within the forest itself but some are located around its periphery. Detailed population information for the region is not available, but the number of households in each clan/village is shown in Table 1.

The villages in the clan of Oum-desaido are in close proximity to one another, differing only in their numbers of residents, and from this point forth will be grouped as one village, referred to by the name of the clan. The village of Hamboka is technically just outside the province of Day but its residents may use the Forêt du Day (H. Rayaleh, Ministry for the Environment, Djibouti, pers. comm.).

Table 1 Summary of the villages and clans in the province of Day. Information obtained from A. Dabaleh, the chief of the Day province.

Clan	Villages	No. households
Elebineto	Day Goub	80 21
Tikito	Tikito	50
Hamoda	Dokh-afe Waydarime	52 (total)
Oum-desaido	Gabladigue Asadaba Gagabagou	37 (total)
Garoda	Moudaa	40
Hamboka (not in Day province)	Hamboka	10
Total	10	290

No research has been conducted on the usage of the Forêt du Day by the inhabitants of the region, and the extent of anthropogenic disturbance has not previously been investigated or quantified.

1.3.2 *The role of local and national government in conservation*

Djibouti is a signatory to the Convention on Biological Diversity (CBD), the Convention on International Trade in Endangered Species (CITES) and the Convention on Migratory Species (CMS). However, there have been no significant attempts by the government to formally protect its endangered fauna and flora, until now. The World Pheasant Association, based in Fordingbridge, UK, is liaising with the Ministère de l'Habitat, de l'Urbanisme, de l'Environnement et de l'Aménagement du Territoire (Ministry for Habitats, Town Planning, the Environment and Regional Planning) and a local NGO, Djibouti Nature, to create and implement a conservation action plan for the Forêt du Day and the Djibouti francolin. Research is crucial to form the scientific basis for the action plan.

At a national level, the Forêt du Day is listed as a reserve in government legislation, but apart from this listing, there has been no formal protection of the area to date. At a local level, current traditional management practices of the forest are undocumented and require investigation, as any attempt to conserve the forest will require community participation.

1.4 Problem statement and aims

The Forêt du Day holds one of the few *J. procera* forests in the world, most of which are under threat. The Djibouti francolin, associated with the forest, is now at record low numbers. It is believed that <1000 remain – but a confident population estimate is lacking. The entire ecosystem appears to be becoming progressively degraded, and the possible causes have not been thoroughly investigated. Scientifically-collected data is urgently required to inform policy and devise management plans to ensure survival of the highly threatened francolin population and juniper forest.

The aims of this study are to investigate

- Which factors best predict juniper condition?
- Which factors best predict francolin presence?
- How large is the francolin population in the Forêt du Day?
- Are juniper condition and francolin abundance correlated?
- How do villages differ in their use of forest resources, and can associations be made between human disturbance and francolin abundance and juniper health?
- What is the capacity of villagers to aid conservation of their forest?

By answering the above questions, this report aims to produce a conservation action plan for the Forêt du Day.

1.5 Hypotheses

The null models for the study are listed below, where 'factors' are any measured potential explanatory variables (e.g. altitude, grazing pressure, etc.).

i) No factors significantly explain any variation in juniper health.

ii) No factors significantly explain any variation in francolin presence/absence.

iii) There is no significant correlation between francolin presence/absence and juniper health.

iv) There is no significant difference in francolin sightings and area of sightings between villages.

v) There is no significant difference in forest usage between villages.

2 METHODOLOGY

2.1 Vegetation mapping

2.1.1 *Field methods*

A preliminary walk found that the forest area containing juniper was about 7.5 km^2. Small patches of forest exist outside the study site, but these were not surveyed as they are not dominated by juniper and are not continuous with the main forest habitat. Systematic grid sampling with 20 x 20 m quadrats was used to record tree and shrub species in order to make a plant community map of the study area. Quadrats needed to be equidistant to allow accurate spatial interpolation of data points in the analysis stage. Pilot sampling of 5 quadrats of different size was initially conducted to record the time taken to sample areas of different sizes. An inspection of the terrain and plant communities, and the extent of the forest, resulted in a final quadrat size of 20 x 20 m being chosen. Vegetation appeared patchy in nature and the 20 x 20 m quadrat was the largest quadrat size possible that was representative of the plant species present whilst at the same time being of a size that would allow a large number of quadrats to be surveyed within the time available. In order to obtain a valid representation of the communities present, the sampling resolution, i.e. the number of quadrats in a given area, was increased as much as time would allow. This resulted in quadrats being made at 150 m intervals, on a grid, corresponding to 44.4 quadrats per sq. km, and 330 quadrats being sampled in total. Figure 6 shows the location of each quadrat. The boundary of the study site was determined by the extent of juniper forest.

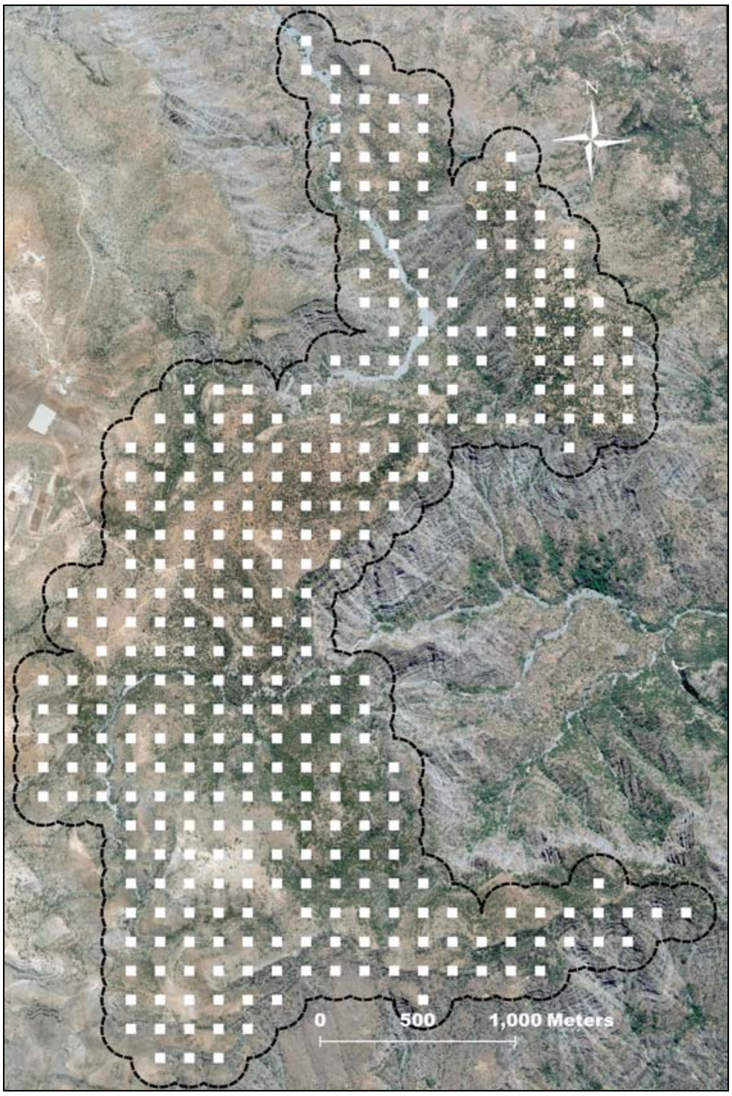

Figure 6 Location of the quadrats shown on a recent satellite image of the forest. The boundary of the study site is indicated by a black dashed line.

There was little bias in the locations of quadrats as few areas were entirely inaccessible, most of which were either fenced exclosures or cliff faces. A GPS[1] was used to navigate to each of the 330 pre-defined coordinates. Due to the openness of the woodland, the accuracy of the GPS was usually always within 5 m. Each coordinate formed the south-western corner of the quadrat, which was then measured out northwards and eastwards using a tape-measure and compass, and its corners marked using flags. The following data were collected for each quadrat:

i) Aspect – the direction the slope was facing. This may be 'none' (plateau), or one of N, NE, NW, S, SE or SW. Aspect could be important for tree health as slopes of different aspects have different microclimatic attributes.

[1] Garmin 12 XL, Olathe, KS, USA (1998).

ii) Slope of the terrain, measured using a clinometer. This was recorded as it could influence microclimate or plant community composition.

iii) Altitude (using the GPS). The GPS was calibrated daily against a known altitude.

iv) Grazing pressure, taken as a proxy from the number of piles of droppings from cows or other livestock. This was recorded on a scale of 0 to 4, where 0, 1, 2 and 3 represent the number of piles of droppings, and 4 represents 4 or more. This scale was defined based on information gained from conducting pilot quadrats in different areas, which showed that the average maximum number of droppings per quadrat was 4.

v) Number of individuals of each species of tree and shrub present. A shrub was defined as a bush or large herbaceous plant 1 m or more in height. It was assumed that tree and shrub species would be representative of the other herbs present when defining plant communities in the final analysis. A field guide prepared by myself using photographs of common plants in Djibouti was used for species identification. In many cases, plants could not be identified on site; photographs were taken and the plants were identified at a later date by Dr. S. A. Ghazanfar in the Africa Drylands team at Royal Botanic Gardens, Kew.

vi) Percentage crown cover for each tree species, to the nearest 5 %, was estimated by eye, as shade could be an important factor for ground-dwelling animals such as the Djibouti francolin.

vii) Condition of each juniper tree in the quadrat was estimated by eye using a five-point semi-quantitative scale between 0 and 4, as defined by Fisher (1997): 0 represented a dead tree, and 1, 2, 3 and 4 represented 25, 50, 75 and 100%, respectively, of branches with living foliage, with trees placed in the nearest category. For each quadrat the mean juniper condition was calculated.

viii) For each living juniper, height was estimated by eye to the nearest metre. Calibration was carried out using trigonometry at the end of the study to compare estimated tree height with actual tree height. For each quadrat, mean juniper height was calculated.

ix) Percentage cover of bare rock, bare soil, grasses and herb species was each estimated by eye to the nearest 5%.

For estimates that required percentage cover by eye, potential bias is introduced into the results. This may be due to over- or under-estimation, depending on the location and topography of the quadrat. Due to the heterogeneity of habitats sampled, it was difficult to calibrate percentage cover estimates across the field. To alleviate the bias in some of the analysis, tree cover estimates are cut into intervals for the francolin model (see later). For other analyses, it must be accepted that bias may be present.

2.1.2 *Plant community analysis*

TWINSPAN (Hill and Smilauer, 2005a) was used to order the 330 quadrats according to the numbers of different species they each contain. TWINSPAN uses ordination and dichotomization to split up groups of quadrats according to their similarities in species composition (see Hill and Smilauer (2005b), for a full explanation of TWINSPAN's methods). This software was chosen as it produces distinct plant community groups from a large dataset and provides indicator species for each plant community. An appropriate set of cut-off levels to be used in the TWINSPAN analysis were determined by observing a histogram of the counts of each plant species. The cut levels used were 0, 2, 3, 5, 8, 15 and 28.

The TWINSPAN output contains main communities but also sub-communities within these. A decision needed to be made regarding which level of division would be used to define each plant community. To aid this decision, the TWINSPAN results were interpreted by cross-referencing with a recent satellite image, acquired on 6th May 2006, with a resolution of 2 feet per pixel. Different combinations of plant communities were overlaid on the satellite image. The final plant communities chosen were those that spatially matched the communities on the satellite image. This method ensured that plant communities described by TWINSPAN were ground-truthed before being used in further statistical analyses. A map of plant communities was drawn in ArcGIS (version 9.2) (ESRI, 2006).

2.1.3 *Juniper forest analysis*

The density of dead and living junipers was calculated for each of the main regions in the study area in order to assess the status of the juniper forest and the proportion of living trees remaining. For a visual interpretation of juniper health, ArcGIS was used to produce a contour map of juniper tree condition over the study site by using mean condition values interpolated from each quadrat. The contours were created using the inverse distance weighted method interpolating from the 12 nearest neighbours with a power value of 2.

Generalized linear modelling in R (R Development Core Team, 2007) was used to find the best environmental predictors for juniper condition by initially fitting a maximal model containing all possible explanatory variables: altitude, slope, aspect and grazing pressure. The model was run using the Gaussian family but also the quasipoisson family of error structures, because of likely non-constant variance and non-normal errors in the data. A range of link functions were used in the modelling. Stepwise deletion of model parameters that did not significantly explain any deviance in the model was carried out according to Crawley (2007). The minimum adequate model was chosen based on its Akaike Information Criterion (AIC) value and its structural adequacy, which was determined by checking the behaviour of its residuals and the normality of the data. The following rules were used in model simplification and decisions:

- Models with a lower AIC were chosen over those with a higher AIC.
- Models with normal errors were chosen over those with non-normal errors.
- Models with constant error variance were chosen over those that showed pronounced trends in variance (such as increasing variance with the mean).

Confidence intervals at 95% were produced for each final model parameter by bootstrapping the model with re-fitted random data points 2000 times.

2.2 Francolin surveys

2.2.1 *Field methods*

Francolins were surveyed at the same time each day, between 0600 and 0900 hrs, when they were most likely to be visible and calling (Welch and Welch, 1985). Twenty-six systematically placed transects over the study site were surveyed (Figure 7). Some transects were far away from the camp and were difficult to navigate to. As a result of this, some start points could not be randomized. Other transects were placed parallel to each other, at 300 m intervals, based on a previous estimate of a mean maximum detection distance of 150 m (Bealey et al., 2006).

Basic stratification of transects was carried out according to terrain type, as plant community type was difficult to assess in the field due to the patchy nature of vegetation. Lengths of transect were weighted proportionally between slopes and wadis (70% of total area in study site) and plateaus (30% of total area in study site). Table 2 summarizes the lengths and area covered by the transects on slopes/wadis and plateaus. Truncation of bird observations over 150 m either side of the transect was carried out based on the 150 m mean maximum detection distance.

Table 2 Summary of total transect lengths and estimated total area surveyed for slopes/wadis and plateaus. Area covered is estimated by a maximum strip width of 300 m and taking into account any overlapping areas.

Stratum	No. transects	Combined length (km)	Estimated combined area covered (km^2)
Plateau	8	4.9	1.69
Slope/Wadi	18	12.2	4.78
Total	26	17.1	6.47

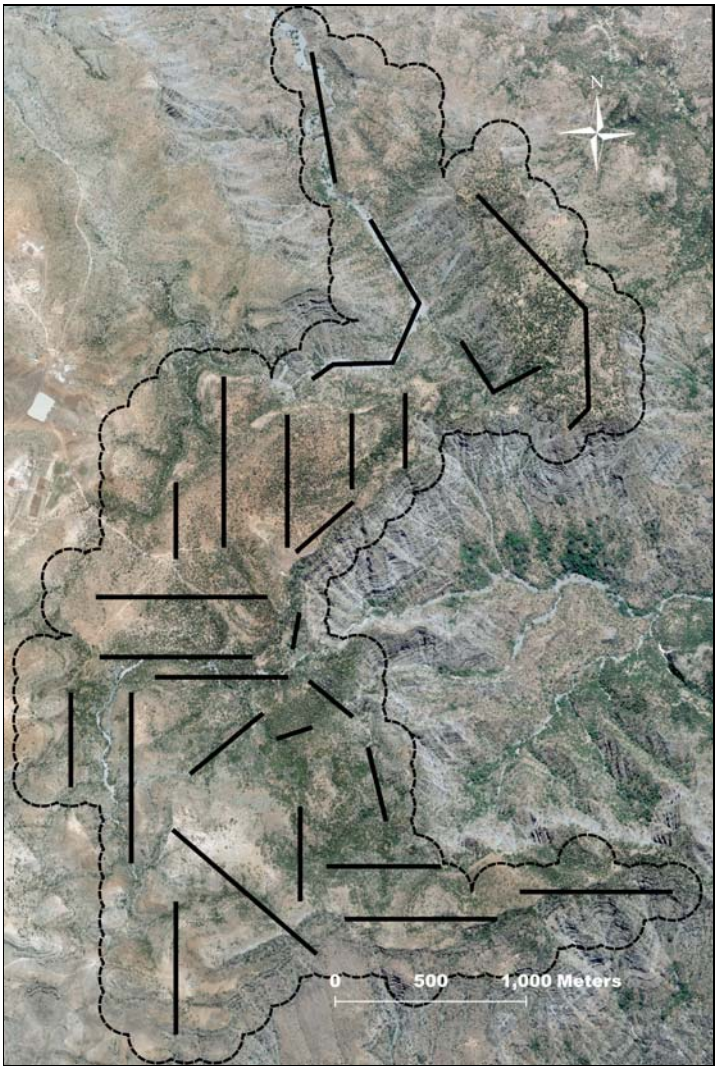

Figure 7 Location of transects in the study site shown on a satellite image. The boundary of the study site is indicated by a black dashed line.

In theory, 6.47 km^2 of area was surveyed by the transects, which is 86% of the total 7.5 km^2 in the study site, but in reality detection distances varied between areas of different topography. It should be noted that due to non-randomization of some start points, possible overlap of some transects due to non-straight geographic features (e.g. wadis), and the large proportion of area covered by the transects, non-independence of some sections of transects is likely to be an issue. Some of this bias can be alleviated in the analysis stage (see later) and this will be discussed further below.

Each transect was walked at a slow but constant pace in a straight line. Longer transects that followed non-straight geographic features such as wadis were later split up into series of straight lines for analysis purposes. Upon encountering a bird sign (visual or audible), the observer's location was noted using a GPS, and the distance to the bird or cluster of birds from the observer, the bearing of the individual(s) from the observer and the cluster size were noted. If possible, the numbers of adults and juveniles in each cluster were also noted. This method was preferred over measuring perpendicular distance from the transect line as birds were easily flushed and it was important to detect birds at their initial location and to ensure a probability of detection on the transect line of 1 (which are assumptions of the DISTANCE model). For the analysis it was assumed that bird detection distances were accurately estimated. To minimise inaccuracy, tests were routinely done to calibrate bird distances by measuring actual distance and comparing with estimated distance. Care was taken to count each bird/cluster only once on each transect by noting the position of each bird encountered. However, birds may move within the transect area during the hours of the morning or between transects sampled on different days. It is not possible to control for this and therefore some bias is introduced into the transect data.

2.2.2 *Analysis of transect data*

DISTANCE (Thomas et al., 2006) was used to produce estimates of bird density, bird cluster density, effective strip width and probability of detection. An estimate of bird density will provide a benchmark for future studies and an estimate of the current population of the Djibouti francolin. Appropriate intervals for bird distances for the analysis were chosen after preliminary inspection of a histogram of bird counts against distance from the transect line. All combinations of models and functions in DISTANCE were fitted to the data and model selection was based on the model with the lowest AIC, as outlined in Buckland et al. (2001).

To create an analysable dataset of presence/absence data for francolins, each transect line was cut into 100 m units in ArcGIS. Each sampling unit had a width of 300 m (based on 150 m truncation either side of the transect line) and thus each had an area of 30,000 m^2. Units of length 100 m were chosen to produce a sufficient sample size for analysis. ArcGIS was used to overlay bird locations on the sampling units. If a sampling unit contained one or more birds, it was given a value of 1, and 0 if no birds were present.

Environmental and biological variables determined from quadrat sampling were also overlaid: Data preparation involved creating continuous contour maps of altitude (Appendix A), grazing pressure, mean juniper condition and percentage total tree cover (Appendix B) across the study site, based on interpolation of the quadrat data points using inverse distance weighting with the 12 nearest neighbours and a power value of 2. Each sampling unit was then given a value for altitude, grazing pressure (a continuous scale from 0 to 4), percentage total tree cover, and mean juniper tree condition (a continuous scale from 0 to 4). Each sampling unit was also given a single plant community type based on the plant community that occupied the majority of the area within the sampling unit.

Generalized mixed linear modelling using the lme4 library in R (Bates, 2007) was used to find the best biological and environmental predictors for bird presence. As the response variable is binomial, strictly bounded between 0 and 1, with likely non-normal errors and non-constant variance, the mixed model was run using the binomial family for data with binomial errors. A maximal model was initially fitted containing the main effects of altitude, grazing pressure, tree cover, mean juniper condition, plant community and inclusion of a random effect for transect number (a number between 1 and 26). This was done to pull out any possible bias in bird presence/absence in relation to the transect.

The models were run using different link functions of the binomial family and a minimum adequate model was chosen based on the same set of rules outlined above in 2.1.3.

Due to a small number of overlapping sampling units at the beginning and end of some transects (due to transect shape in some areas), a small proportion of the total area was effectively re-sampled. For these sampling units, a coin was tossed to decide which sampling unit to include in the dataset (and thus which presences/absences to include). To minimise bias, 10 randomised data sets were created using this method and run from a maximal model, in order to observe any possible variation between the final minimum adequate models and their parameter values.

2.3 Interviews

2.3.1 *Interview methodology*

To explore differences in forest usage between villages, a stratified sample of 37.5% was taken of the 5 villages in the region that utilise the Day Forest. The chief of the province of Day, Abdullah Dabaleh, was approached to obtain recent census information for each village. Table 3 shows the population information and the sample taken form each village.

Table 3 Number of households in each village and sample taken.

Village	Total no. households	No. households interviewed (37.5% of total)
Day	80	30
Tikito	50	19
Goub	21	8
Oum-desaido	37	14
Hamboka	10	4
Total	198	75

Interviews were semi-structured in order to gain the most information possible and each lasted no longer than 25 minutes. The interviewees were typically the male owner of the household. The interviews were conducted with the help of a fluent Afar-French translator, and the questions were designed to be non-leading and sufficiently simple so as not to loose meaning in translation from French to Afar. However, there is potential bias in responses to interview questions based on the different phrasing of questions in Afar and French. To reduce this bias, the translator was informed of the importance of non-leading questions. Households were selected systematically in each village by selecting every third or fourth household along the main village path. If there was no one available to conduct the interview in the household, rather than choosing another, the interview was re-attempted at another time. On no occasion were we refused an interview. To reduce bias in the geographic location of households chosen (e.g. in relation to distance from the forest), care was taken to systematically select households in the whole village area, i.e. not ignoring certain households further away from the main paths. This was easier for smaller villages, but for villages that sprawl out widely, potential bias is introduced in the sampling.

The full interview questionnaire is in Appendix C. The main elements of the interview and their rationale for the analysis are shown in Table 4.

Table 4 Main elements of the interview and rationale behind the questions.

Interview element	Rationale
Age, employment, family information and other past places of residence.	Whether age, employment, family size, or length of residency in the village is correlated with factors such as perceived year of death of juniper forest.
Number of each type of animal owned and regions where they are grazed, observed recent trends in pasture quality, number of births of animals (productivity) and changes in livestock numbers over the last year.	Whether there are significant differences between grazing regions for each village, numbers of livestock, productivity and pasture quality. To find out which regions are grazed most heavily, and by whom. Triangulation to find out if number of births correspond with changes in livestock numbers.
Frequency of sightings of francolins and region sighted, and importance of the francolin to villagers.	Whether there are significant differences between the frequency of sightings of francolins and region sighted between villages. To discover in which areas birds are seen most frequently and which areas birds are perceived as rare.
Perceived year when commencement of juniper forest death started, possible reasons and ideas for management	To find out when the forest started dying, the reasons attributed to tree death and the capacity and willingness of villagers to conserve their forest.

2.3.2 *Analysis of interview data*

To assess differing grazing pressures and livestock between different villages, general log-linear models were used (using the poisson error family) to analyse complex contingency tables of count data according to Crawley (2007), for differences between villages in the following variables:

- Number of animals of each type (0 - 4, 5 - 10, 11 or more);
- Grazing region of animals (region within the forest);
- Trends in pasture quality over recent years (up or down);
- Trends in animal productivity over recent years (up or down); and
- Any higher-order interactions between village and the above 4 variables.

Information on francolin sightings was analysed with general log-linear models using the same method described above. Differences between villages were identified with respect to:

- Frequency of francolin sightings (daily, occasionally or rarely); and
- Most common region where francolins are seen.

The presence of a 3-way interaction between sighting region, frequency and village was also tested for.

Data on perceived year in which forest death commenced were tested for normality and the upper and lower quartiles were calculated to identify the variation in the year given between villagers. Age was correlated with the year to test whether age may influence the perceived year of juniper death.

Finally, the reasons attributed to juniper death and management ideas of all villagers were tallied and plotted.

3 RESULTS

3.1 Baseline vegetation and plant community analysis

Table 5 summarises the output from TWINSPAN, based on 45 species of trees and shrubs found in the 330 quadrats. Eight distinct communities were identified in the TWINSPAN analysis, varying on their level of division. The full TWINSPAN output is summarised in Appendix D.

Table 5 Plant communities and their indictor species.

ID no.	Indictor species	Eco-geographical zone	% of quadrats
A	*Juniperus procera* + *Buxus hildebrandtii* +	Open, mixed woodland No shrub cover Slopes Mid-range altitude	4.8%
B	*Juniperus procera* + *Tarchonanthus camphoratus* + *Psidia punctulata* + *Withania somnifera* + *Euryops arabicus* –	Open, mixed woodland Moderate shrub cover Slopes Mid-high altitude	6.7%
C	*Euryops arabicus* + *Psidia punctulata* + *Tarchonanthus camphoratus* +	Open, mixed woodland Shrub-dominated Slopes and plateau Mid-high altitude	12.7%
D	*Juniperus procera* + *Olea europaea* + *Sideroxylon mascatense* + *Buxus hildebrandtii* –	Dense, mixed woodland Moderate shrub cover Slopes and plateau High altitude	18.9%
E	*Buxus hildebrandtii* + *Withania somnifera* +	Dense *Buxus* woodland Low shrub cover Slopes and plateau Mid-range altitude	21.8%
F	*Nicandra physaloides* + *Withania somnifera* + *Buxus hildebrandtii* + *Sideroxylon mascatense* – *Olea europaea* – *Euryops arabicus* –	Open *Buxus* woodland High shrub cover Plateau Mid-range altitude	18.1%
G	*Euryops arabicus* + *Nicandra physaloides* + *Buxus hildebrandtii* + *Olea europaea* – *Sideroxylon mascatense* –	Open, mixed woodland Shrub-dominated Plateau Mid-range altitudes	4.2%
H	*Acacia seyal* + *Indigofera coerulea* + *Juniperus procera* –	Open, mixed woodland Low shrub cover Wadis Lower altitudes	12.4%

Figure 8 shows the altitudinal and slope range of each community. Some plant communities appear to show distinct altitudinal bands, and those that overlap greatly, such as F and G, are different in their slope range. These preliminary results indicate that altitude plays a larger role in separation of different communities than slope.

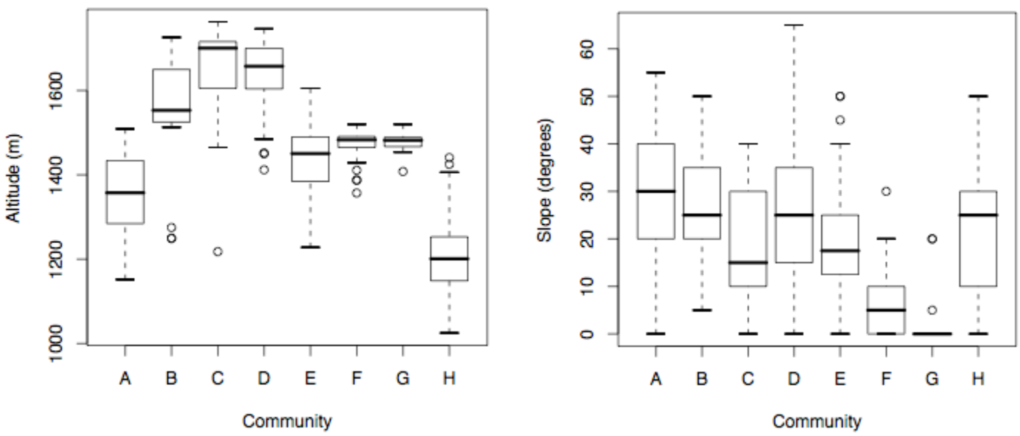

Figure 8 Altitudinal range and slope range of each plant community.

Figure 9 shows the occupancy of the eight plant communities in the study area. The southern areas of the forest are dominated by communities C and D, which are at a high altitude of c. 1500 – 1750 m as shown in Figure 8. Community D, in the south-east, is dominated by juniper and olive, and box is absent. Community C, in the south-west, occupies the Barabarre plateau and is more open than community D, with high shrub cover and the dominant tree being *Tarchonanthus camphoratus*. The satellite image in Figure 3 clearly shows the high level of aridity in this zone.

Dense *Buxus* woodland dominates the slopes of the Barabarre mountain (communties A and E), mixed with juniper in some areas (c. 1450 – 1600 m). These areas have variable shrub cover, depending on the thickness of the forest.

Community F covers most of the Garab plateau (c. 1470 m), which is an open *Buxus* woodland, characterised by the vast number of dead junipers. It is evident that this region was once a closed-canopy juniper forest, but it is now covered with grazing-tolerant shrubs such as *Nicandra physaloides* and *Withania somnifera*. Due to the openness of the habitat (Figure 3), the plateau is very arid and many clearings are present.

The Adonta region (c. 1250 – 1350 m) is covered by a dense *Buxus* forest in the south (community E) and an open *Acaica seyal* woodland in the north (community H). The Adonta region is drier because of its lower altitude, but it supports diverse vegetation on its hilly plateaus and varying topography types. It also has very thick herb cover throughout. There is barely any living juniper left in the Adonta region, with dead trees covering the landscape.

The Hamboka region is at the lowest altitude (c. 1000 – 1250 m), and is dominated by *Acacia seyal* (community H). Juniper is absent. The cliff vegetation is diverse and very different from other areas in the forest, benefiting from the Hamboka wadi, which is one of the largest in the province of Day and collects a lot of water from the Garab plateau.

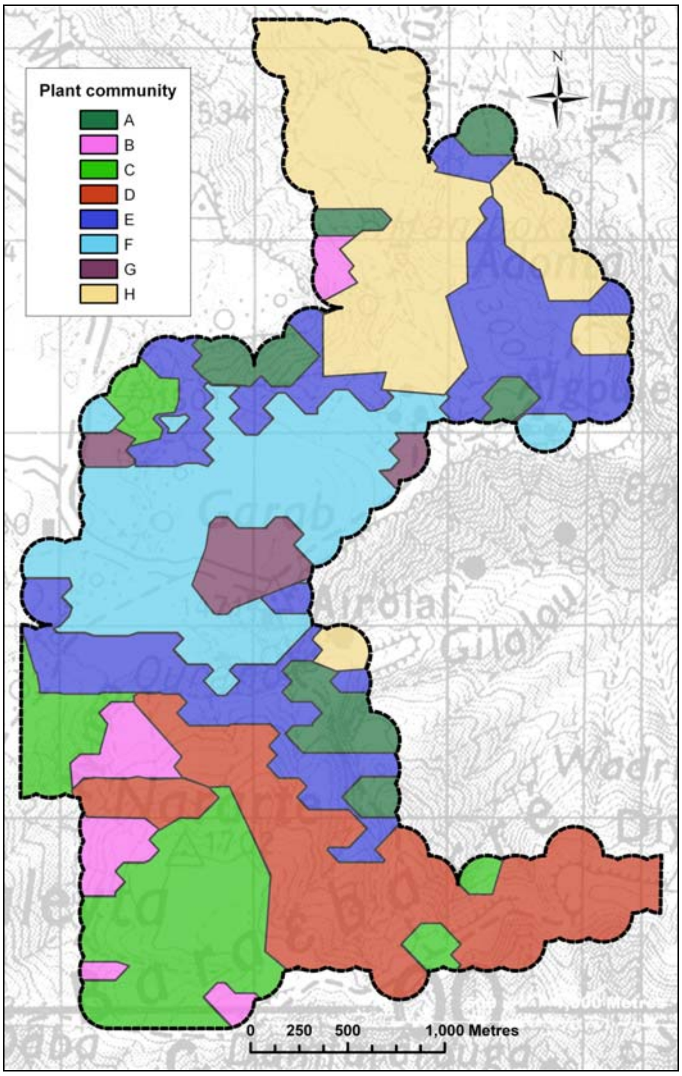

Figure 9 Plant community map.

3.2 Condition of juniper forest

3.2.1 *Grazing intensity*

Grazing pressure is highest on the Garab plateau and the Barabarre plateau. Grazing pressure decreases towards the east (away from the villages in the west) on Barabarre and Adonta. On the northern and western slopes of Barabarre, grazing intensity is also lower, but increases again as slopes level out to plateau (Figure 10).

Grazing intensity is therefore not spread evenly across the region, but is biased to the western edge of the forest. Possible reasons for this include the distance travelled by animals to reach pasture, the quality and sufficiency of pasture, and ease of access to certain areas. The Adonta plateau has a low overall grazing intensity, but it became apparent through interviews that a traditional management system is in place that allows grazing on Adonta in only one season (summer). At other times grazing is forbidden. At the time of the study, the plateau had not yet been opened to cattle (a fenced barricade stops animals from crossing), which is why it had such a low grazing score. Long grass and thick herb cover was also noted in the zone. The abundance of francolins in this zone may be due to the absence of livestock, although this is not evident from the MAM (grazing is only an interaction term). However, it is likely that opening of the Adonta plateau in the grazing season could affect the resident francolins in some way.

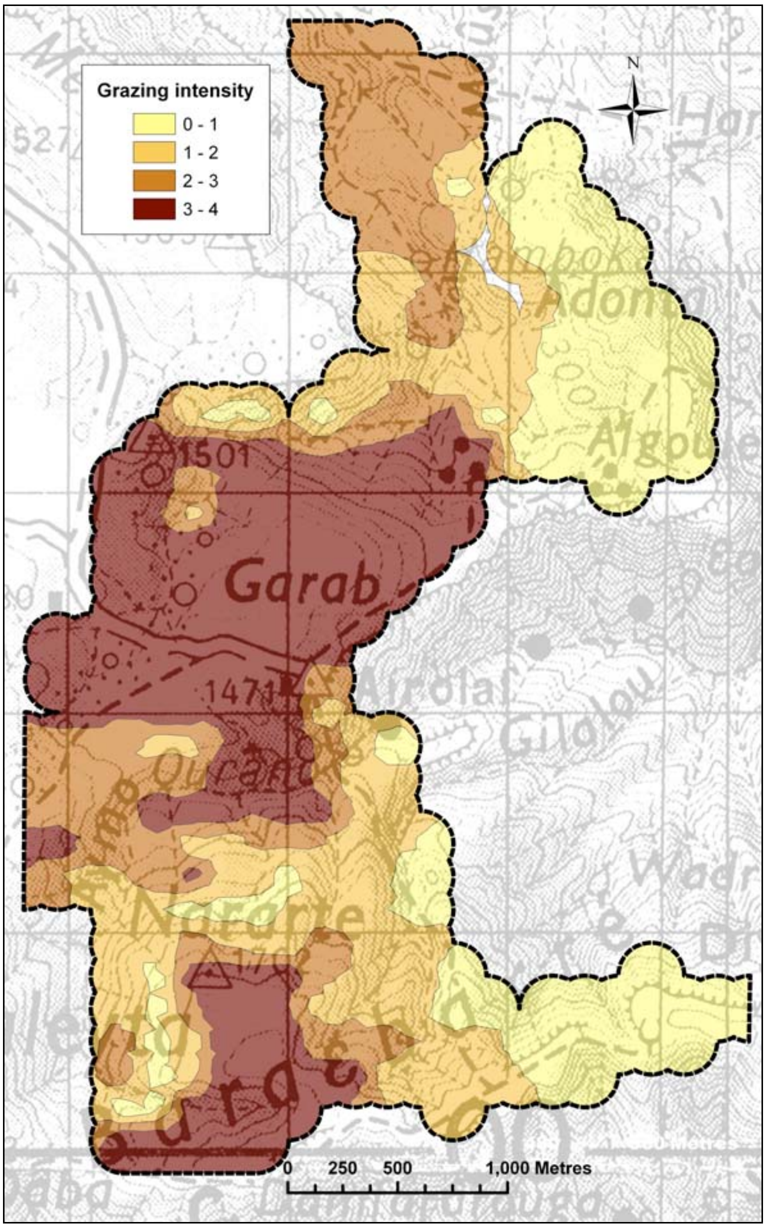

Figure 10 Contour map of grazing intensity (semi-quantitative scale) in the study site. The dashed black line indicates the edge of the study area.

3.2.2 *Status of juniper forest*

Figure 11 shows the density of living and dead *Juniperus procera* in the five main geographic regions of the study site. The highest density of junipers is on the eastern part of the Barabarre mountain. This region has the highest density of living trees but also of dead trees. All other regions have significantly fewer trees per hectare, and also all have more dead trees than living trees.

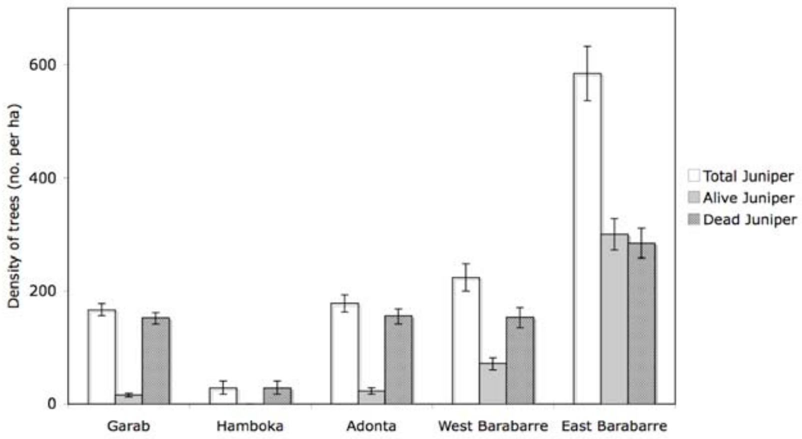

Figure 11 Mean density of junipers in five main regions.

Table 6 shows the mean percentage of living juniper trees and the mean tree condition in each of the regions. Mean condition is shown as a percentage of the tree that is still living, converted from the original 0-4 scale, averaged from each quadrat. Although east Barabarre has the highest proportion of living junipers (51.3%), on average, tree condition is only 60.6%. The region with lowest tree condition and percentage of living juniper is Garab, where less than 10% of junipers are living, and of these, the mean condition is just 44.3%. Hamboka has no living junipers.

Table 6 Mean percentage of living juniper and mean condition in five main regions.

Region	% Living juniper	Mean % condition	Std. error of mean condition	No. of quadrats
Garab	8.9	44.3	3.5	95
Hamboka	0	0	0	41
Adonta	12.7	57.5	3.3	44
West Barabarre	31.8	61.3	1.6	57
East Barabarre	51.3	60.6	0.8	93

Figure 12 illustrates the geographic trend in condition of juniper trees. Condition is highest (tree health above 50%) on the eastern part of the mountain Barabarre, which is at a high altitude. The northern slopes of Barabarre, shown on the map as 'Nararte', and west Barabarre have a lower mean condition of 1 – 2 (25 to 50%). The plateau forests of Garab and Adonta are uniformly at a low overall condition between 0 – 1 (0 to 25%).

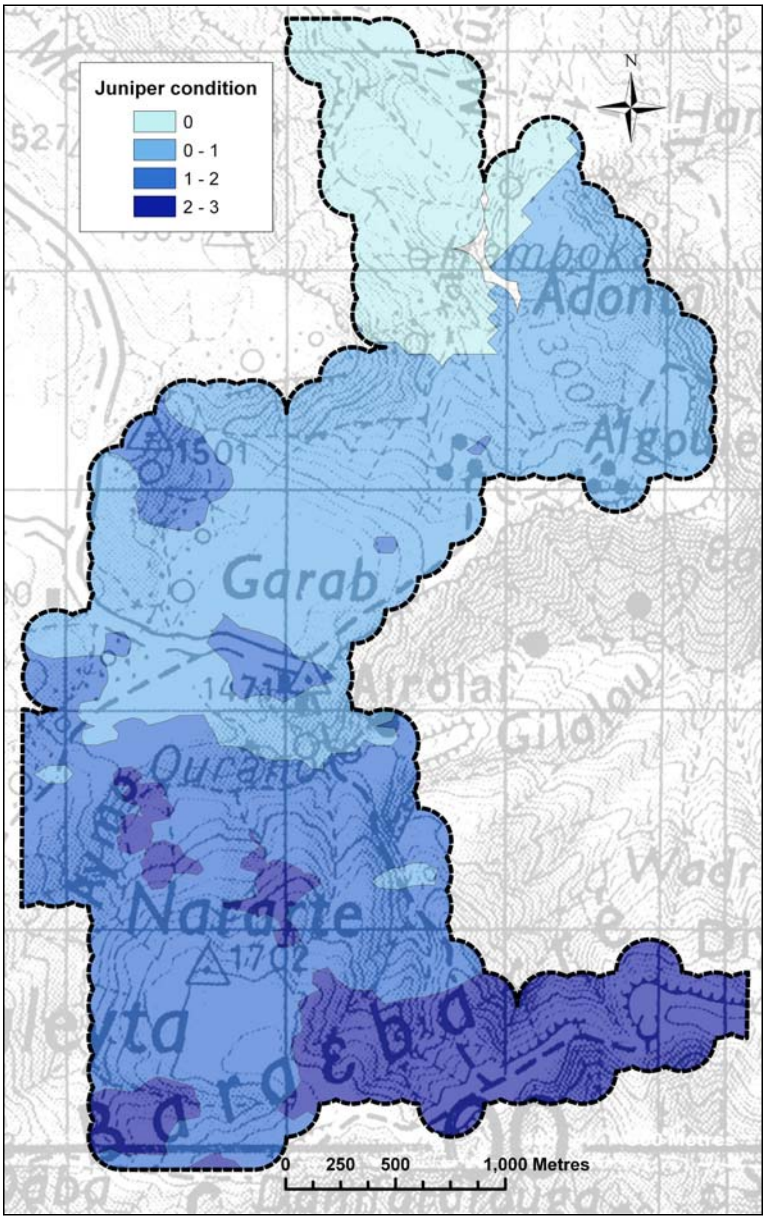

Figure 12 Contour map showing mean condition of juniper. The dashed black line signifies the edge of the study area.

3.2.3 *Data structure*

A correlation matrix of the measured continuous explanatory variables is shown in Table 7 and results of one-way ANOVAs for the categorical variables (plant community and aspect) against the measured continuous variables are shown in Table 8. In addition, plant community is significantly associated with aspect ($\chi^2 = 151.23$, *d.f.* = 56, $p<0.001$).

Table 7 Pearson correlation matrix of continuous variables. Numbers in bold represent significant correlations (*p*<0.05, with Bonferoni correction).

	Altitude	Slope	Grazing	Herb cover	Tree cover	Dead juniper	Total juniper	Alive juniper	Juniper cover	Mean height	Mean condition
Altitude	1.00										
Slope	-0.04	1.00									
Grazing	0.08	**-0.45**	1.00								
Herb cover	0.16	0.14	**-0.39**	1.00							
Tree cover	0.04	**0.29**	**-0.33**	**0.32**	1.00						
Dead juniper	**0.46**	-0.15	-0.13	**0.36**	0.22	1.00					
Total juniper	**0.54**	-0.02	**-0.24**	**0.43**	**0.39**	**0.88**	1.00				
Alive juniper	**0.49**	0.12	**-0.30**	**0.38**	**0.46**	**0.54**	**0.87**	1.00			
Juniper cover	**0.42**	0.14	**-0.26**	**0.36**	**0.51**	**0.41**	**0.74**	**0.89**	1.00		
Mean height	**-0.47**	-0.16	0.14	0.03	0.09	**-0.23**	**-0.26**	**-0.23**	-0.07	1.00	
Mean condition	**0.48**	**0.27**	**-0.30**	0.17	**0.31**	0.07	**0.46**	**0.71**	**0.70**	**-0.24**	1.00

Table 8 Results of one-way ANOVAs for aspect and plant community against the measured continuous variables. Probabilities are shown; those highlighted in bold type are less than 0.0025, for a Bonferoni correction with 20 comparisons.

Continuous variable	Plant community (*d.f.* = 7)	Aspect (*d.f.* = 8)
Altitude	**<0.001**	**<0.001**
Slope	**<0.001**	**<0.001**
Grazing	**<0.001**	**<0.001**
Herb cover	**<0.001**	0.0068
Tree cover	**<0.001**	**<0.001**
Dead juniper	**<0.001**	**0.0011**
Alive juniper	**<0.001**	0.020
Total juniper	**<0.001**	0.0026
Juniper cover	**<0.001**	0.017
Mean height	**<0.001**	0.37
Mean condition	**<0.001**	0.11

Plant community is significantly correlated with all the other measured variables. This is because variables such as number of junipers, juniper cover, juniper condition and height, herb cover and total tree cover are responsible for the differences in plant communities. However grazing, altitude, slope and aspect are also significantly correlated with plant community. Altitude and slope have been discussed earlier, but it is not surprising that aspect and grazing also differ between plant communities. For example, those communities on slopes usually have the same aspect and share other characteristics such as grazing intensity. The spatial separation of plant communities by region (Figure 9) is thus likely to be the reason why the other variables correlate so highly with plant community.

Aspect is also confounded by altitude, grazing and slope. This is probably an artefact from the areas surveyed and the topography of the region. For example, each quadrat on a plateau will have a similar altitude and the same aspect (none), and the highest altitudes surveyed were mostly north-facing, grazed less and steeper.

The tree model in Figure 13 suggests that altitude accounts for the majority of the deviance in mean condition, followed by grazing pressure. The right fork of the tree accounts for 65% of the 274 quadrats in the dataset (Table 9), and high altitudes have a higher tree condition. At altitudes above 1561m, low grazing (<2.5) is associated with better tree condition (mean = 1.15), but tree condition is also high on north-east, south-west and west facing slopes (mean = 1.28), despite higher grazing.

As with high altitude, for trees below 1561m, condition is lowest at grazing levels above 2.5 (mean = 0.18). At lower grazing levels, altitude continues to explain most of the deviance. The lowest altitudes (<1444m) have a low tree condition of 0.23. At intermediate altitudes (between 1444 and 1479 m), tree condition is higher with a mean of 1.64. Juniper trees facing north-west, north-east and south-east have a lower condition than those facing other directions at altitudes above 1479 m.

Slope angle doesn't feature in the tree model and thus explains minimal deviance in tree condition. Altitude and grazing explain most of the deviance.

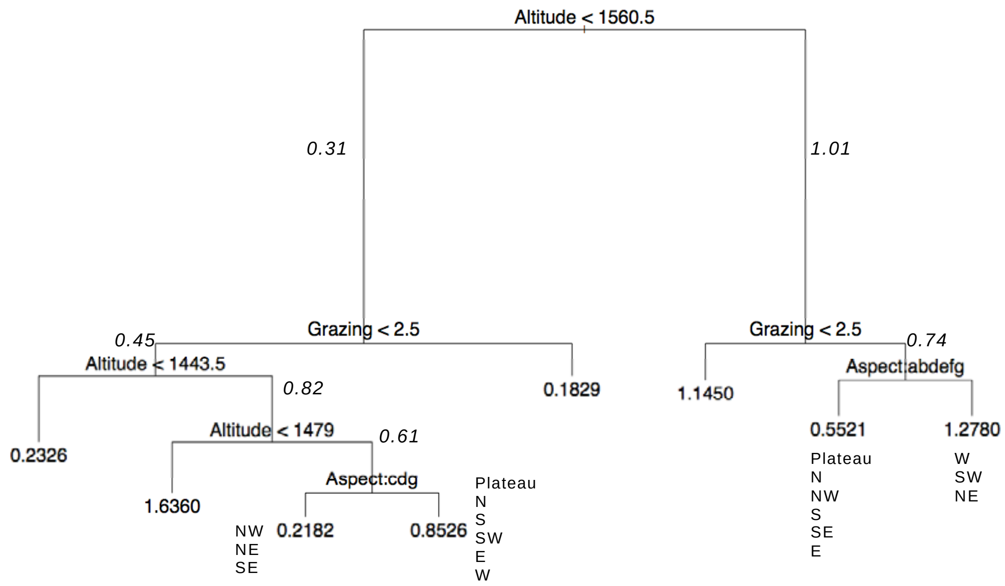

Figure 13 Tree model showing explanatory variables in relation to mean condition of junipers. Numbers in italics are mean juniper condition at inter-nodal divisions. At each division, 'yes' is on the right-hand fork.

Table 9 Number of quadrats, deviance and mean juniper condition at each node of the tree model. Stars indicate terminal nodes.

Node and split	n	Deviance	Mean
1) root	274	112.70	0.55
2) Altitude < 1560.5	177	44.13	0.31
3) Grazing < 2.5	81	33.97	0.45
5) Altitude < 1443.5	51	8.06	0.23*
5) Altitude > 1443.5	30	19.41	0.82
7) Altitude < 1479	6	5.62	1.64*
7) Altitude > 1479	24	8.78	0.61
8) Aspect: NE,NW,SE	9	0.88	0.22*
8) Aspect: P,E,N,W,SW	15	5.64	0.85*
3) Grazing > 2.5	96	7.03	0.18*
2) Altitude > 1560.5	97	37.94	1.01
4) Grazing < 2.5	63	22.20	1.15*
4) Grazing > 2.5	34	12.19	0.74
6) Aspect: P,E,N,NW,S,SE	25	4.40	0.55*
6) Aspect: W,SW,NE	9	4.30	1.28*

3.2.4 *Minimum adequate model for juniper condition*

The minimal adequate model (MAM) for mean condition of junipers is given by the formula:

log(Mean condition + 1) ~ Altitude + Altitude : Grazing + Grazing : Slope

This generalized linear model was fitted using the Gaussian family and the "identity" link function, the combination of which provided the best fit and the lowest AIC. The full maximal model and the subsequent models are shown in Appendix E. Log-transforming the response variable greatly reduced the residual deviance and +1 was added to each value due to the large number of zeros in the dataset. Table 10 summarizes the model parameters, and Table 11 gives the results from bootstrapping the model by refitting 2000 times with random data points.

Table 10 Minimum adequate model for mean condition of junipers (*** = p<0.001, ** = p<0.01, * = p<0.05). AIC = 126.05, null deviance = 38.88 on 273 degrees of freedom, residual deviance = 24.50 on 270 degrees of freedom.

	Coefficient	Standard error	*t* value
Intercept	- 2.032 ***	2.370e-01	- 8.573
Altitude	0.001671 ***	1.566e-04	10.674
Altitude : Grazing	- 6.054e-05 ***	8.536e-06	- 7.092
Grazing : Slope	0.001642 **	6.347e-04	2.587

Table 10 shows that mean condition of junipers is positively and significantly correlated with the main effect of altitude, and there are two significant interactions retained in the MAM. The null hypothesis i), that no factors significantly explain any variation in condition of junipers, is therefore rejected. However, mean condition did not show a significant correlation with aspect and aspect does not feature in the MAM, so the null hypothesis is accepted for this variable.

These results differ from those shown in the tree model: Slope did not feature in the tree model. Tree models are an exploratory tool and even though slope did not explain any significant variation in mean condition in the tree model, the tree model does not look for interactions between the variables, which have been highlighted in the MAM. Furthermore, aspect appeared in the tree model but not in the MAM; in the tree model aspect only explains a small amount of deviance (Table 9), which was not found to be a significant amount in the MAM.

Table 11 Ordinary nonparametric bootstrap statistics for the juniper model with bias-corrected, accelerated confidence intervals at 95%.

	Bias	Bootstrapped std. error	Lower CI	Upper CI
Intercept	7.947e-04	2.362e-01	-2.485	-1.545
Altitude	4.960e-08	1.528e-04	0.001345	0.001954
Altitude : Grazing	-1.675e-07	7.268e-06	-7.531e-05	-4.665e-05
Grazing : Slope	2.758e-05	6.411e-04	0.0003482	0.002832

The bias in all four parameters is very low (Table 11), and the bootstrapped standard errors are close to their parametric estimates shown in Table 10.

Figure 14 investigates the structure and adequacy of the model. A strong line appears in the residuals vs. fitted values plot, which is an artefact from the large number of zero values in the dataset. Otherwise, there is no suggestion of non-constant variance. The normal Q-Q plot confirms that there is a straight-line relationship between the model's standardized residuals and theoretical quantiles derived from a normal distribution, and thus there is no indication of non-normality in the residuals.

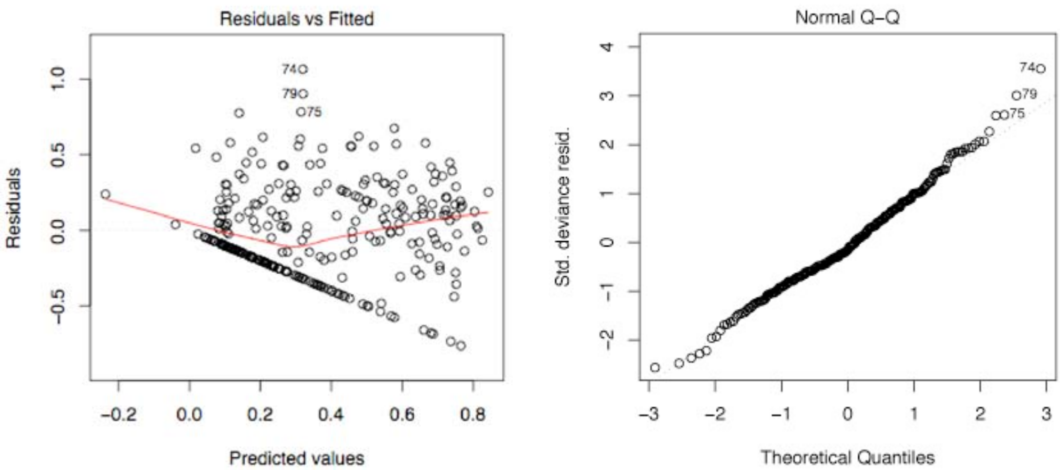

Figure 14 Plotted residuals against fitted values and normal plot of the juniper condition model.

Figure 15 explains the significant correlation between mean condition and the main effect of altitude (black line) and the altitude : grazing interaction (blue and red lines). At all altitudes there is a high number of dead trees (mean condition = 0). Below 1300 m, there are no living junipers. As altitude increases from 1300 to 1800 m, mean condition of junipers increases. It is also evident from Figure 15 that there are patches of high grazing (red) around 1500 m and 1700 m.

The altitude : grazing interaction is such that at a given altitude, a higher juniper condition corresponds with lower grazing levels. Therefore, grazing is having a negative effect on condition of junipers, mediated through altitudinal differences. The (horizontal) difference in altitude between the low and high grazing trendlines is about 200 m. Thus, on average, a tree in a heavily grazed area will be 200 m higher in altitude than a tree of the same health in a lightly grazed area. The (vertical) difference in mean condition between the low and high grazing trendlines is about 0.4, corresponding to a change in mean condition of 1, or 25%. Thus, on average, at a given altitude, trees in heavily grazed areas will be 25% less healthy than those in lightly grazed areas.

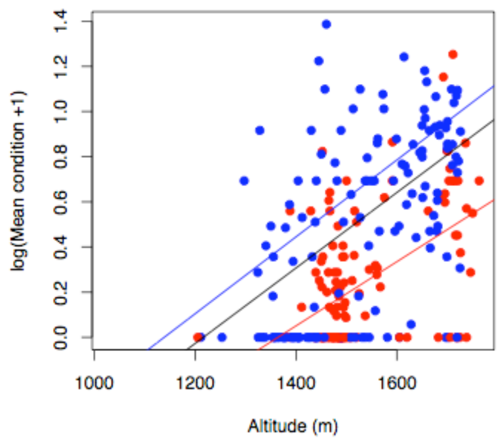

Figure 15 Mean condition of junipers as predicted by the main effect of altitude and the altitude : grazing interaction (black line = model, blue line (and data points) = trendline for when grazing<2.5 , red line (and data points) = trendline for when grazing>2.5).

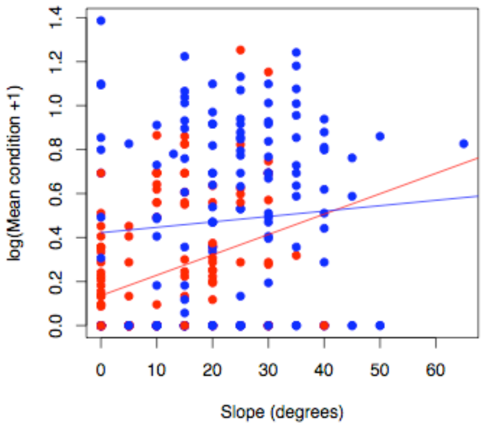

Figure 16 Mean condition of junipers as predicted by the grazing : slope interaction (blue line = trendline for when grazing<2.5 , red line = trendline for when grazing>2.5).

The interaction between grazing and slope is shown in Figure 16. At high grazing (>2.5, red), juniper condition increases with slope, but at low grazing (<2.5, blue) the increase in condition with slope is very slight. It appears that slope affects juniper condition more in areas of high grazing than in areas of low grazing. As slope increases, the difference in the effects of low and high grazing become less and less obvious, shown by the converging trendlines at about 40 degrees. There are too few observations on steep slopes (>40 degrees) to draw attention to any relationship here. However, on less steep slopes (<40 degrees), the effects of grazing on juniper condition is most pronounced on the gentle slopes.

3.3 Status of the Djibouti francolin

3.3.1 *Transect survey results*

The field data comprised of 54 observations of clusters of francolins on 26 independent transects. Of these, 31 were audible observations (with unknown cluster sizes) and 23 were visual observations (known cluster sizes ranging from 1 to 5). With visual and audible observations combined, a minimum of 89 birds were recorded from the transect data. Figure 17 shows the locations of the bird clusters on a recent satellite image. Francolins were not found uniformly throughout the Day Forest, but rather in isolated patches. Specifically, they were absent from most of the Garab plateau and the western plateau on Barabarre. There are two distinct areas where clusters of birds were aggregated: the Adonta region in the north, and on the north facing slopes of the Barabarre mountain.

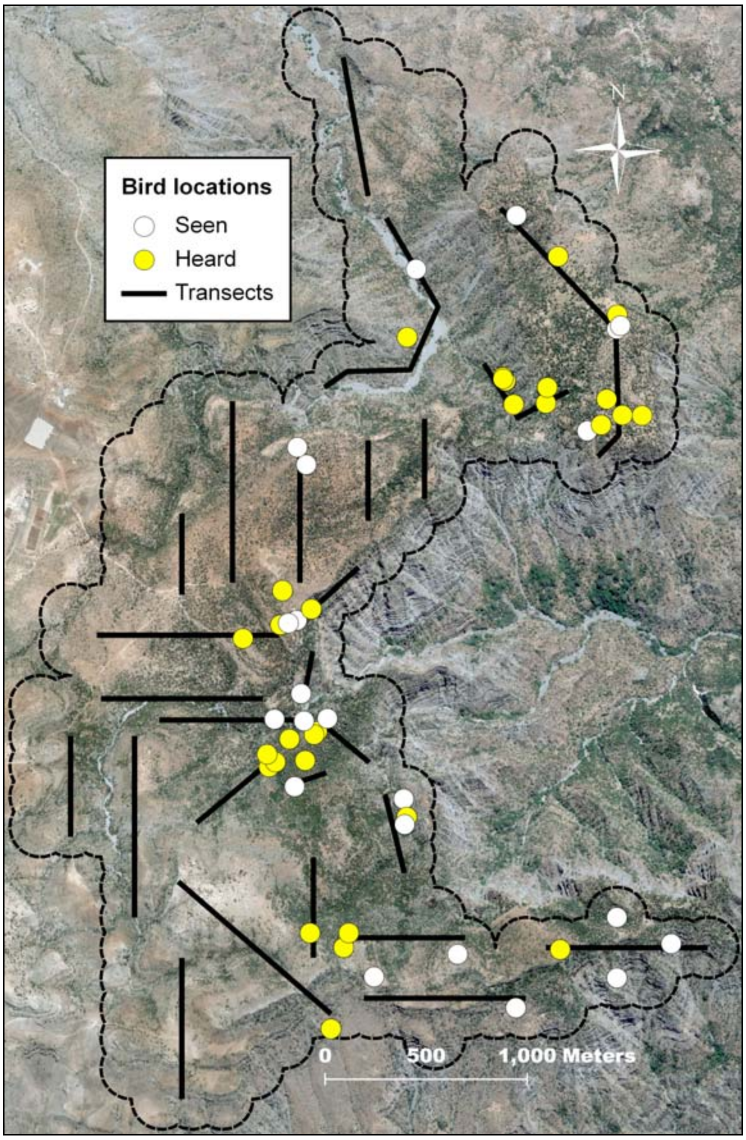

Figure 17 Locations of bird clusters in relation to transects in the Day Forest.

Using DISTANCE, the two data sets (visual and audible observations) were initially analysed separately, but had the same best model in common (with the lowest AIC): half-normal with a cosine function. They also showed a very similar trend in probability of detection. For these reasons the two data sets were pooled for a more robust, combined DISTANCE analysis. For analysis of cluster sizes, only visual observations were included.

The resulting model with the lowest AIC (of 198.05) was half-normal, fitted with a cosine function. The data were not truncated, as truncation of the data at 150 m already occurred in the field. Twelve equal intervals were chosen, based on preliminary observation of the distribution of distances. The model fit the data closely in a goodness of fit test ($\chi^2 = 9.35$, $d.f. = 9$, $p = 0.41$). Figure 18 plots the probability density function against the model.

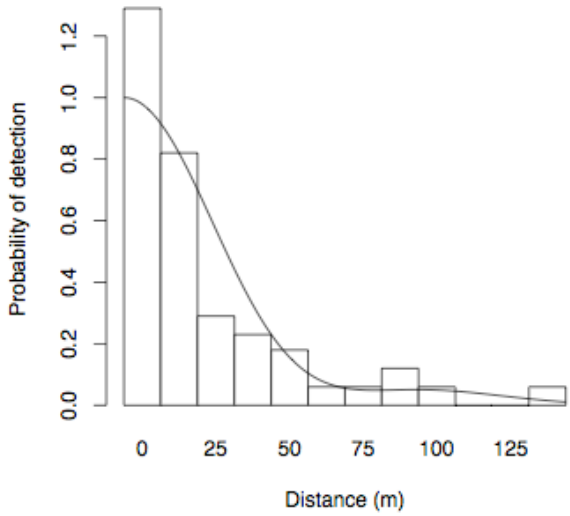

Figure 18 Detection probability against distance showing the fitted model as a line.

Table 12 shows the output of the DISTANCE analysis. Mean and expected cluster sizes are 1.21 and 2.69, respectively, with an estimated 33 clusters per sq. km. The expected cluster size is significantly larger than the mean cluster size. This suggests that many larger clusters were not observed (i.e. above the detection function). This should be noted in future studies. The density of francolins is estimated at 90 per sq. km in the study area, but a 95% confidence interval indicates that there may be between 51 and 157 francolins per sq. km. Effective strip width was estimated to be 39 metres.

Table 12 DISTANCE analysis using a half-normal model with a cosine function showing 95% confidence intervals. Mean cluster size and expected cluster size were calculated using only the visual observations.

	Estimate	d.f.	Std. error	% coefficient of variation	Lower CI	Upper CI
Probability of detection per location	0.26	52	0.024	9.05	0.22	0.32
Effective strip width (m)	39.45	52	3.57	9.05	32.91	47.29
Density of birds (no./km^2)	89.63	62.35	25.71	28.68	51.09	157.21
Density of clusters (no./km^2)	33.32	42.14	8.21	24.63	20.42	54.37
Mean cluster size	1.21	23	0.39	32.56	1.00	2.33
Expected cluster size	2.69	22	0.40	14.70	1.99	3.64

3.3.2 *Data structure*

The tree model in Figure 19 and Table 13 suggests that grazing pressure explains most of the deviance in bird presence. Lower grazing levels (<1.85) have a mean presence of 0.37 and higher grazing levels (>1.85) have a mean presence of 0.10. At both high and low grazing, tree cover is the next most important variable. Where grazing and tree cover is high (>55%) mean presence is 0.5, but when grazing is high and tree cover is low (<55%), mean bird presence is just 0.09. The latter split accounts for 74% of the 235 observations, and thus requires investigation. Mean condition explains most of the deviance at this level, with high mean condition (>2.59) associated with a mean presence of 0.25. However, only 12 observations are included here (Table 13), and the remaining 161 are at a lower mean condition (<2.59). Of these, altitude explains most of the deviance with only absences noted above 1403 m, and a mean presence of 0.12 below 1403 m.

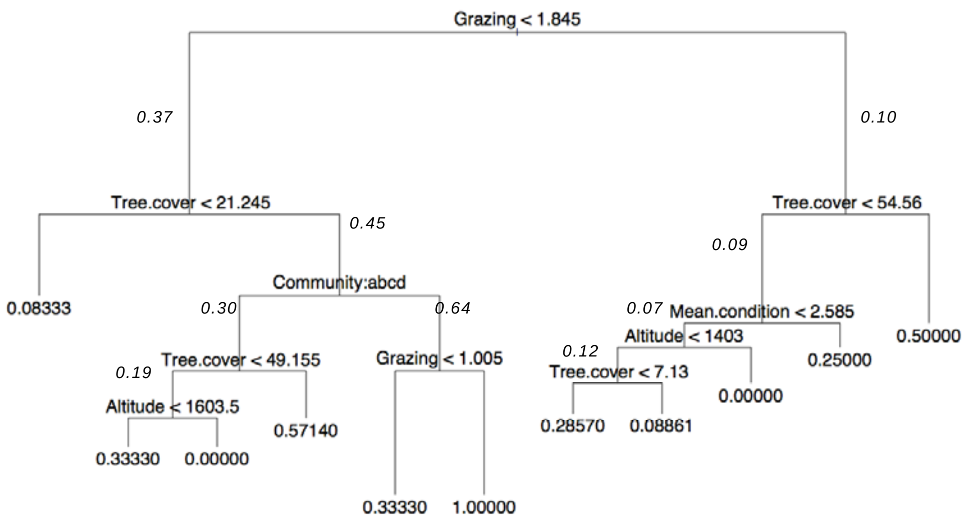

Figure 19 Tree model showing explanatory variables in relation to bird presence/absence. Numbers in italics are mean bird presence at inter-nodal divisions. At each division, 'yes' is on the right-hand fork.

Returning to the root of the tree, it is evident that when grazing is low (<1.85) and tree cover is low (<21%), bird presence is very low (mean = 0.08). However, at low grazing and high tree cover (>21%), mean bird presence is 0.45. At this level, plant community explains most of the deviance: bird presence is higher (0.64) in community E (dense box woodland) and H (open *Acacia seyal* woodland), and lower (0.30) in communities A, B, C and D, which are mainly mixed open woodlands containing junipers. High tree cover (>49%) is important for birds in communities A, B, C and D, while high grazing pressure (>1.0) is associated with presence of francolins in communities E and H, although the latter division only contains 8 observations with no deviance explained in the split (Table 13).

The tree model should only be judged as an exploratory tool for showing structure in the data. However, these preliminary findings suggest that grazing and tree cover may have a strong influence on francolin presence. Francolin abundance may also be associated with box and acacia woodland, the majority of which is degraded forest, but Table 13 shows that plant community only explains a small amount of deviance (as does altitude).

The variable of transect number did not feature in the tree model, indicating that it explains a minimal amount of deviance in relation to presence of francolins.

Table 13 Number of quadrats, deviance and mean bird presence at each node of the tree model. Stars indicate terminal nodes.

Node and split	n	Deviance	Mean
1) root 235	235	31.86	0.16
2) Grazing < 1.845	52	12.06	0.37
3) Tree cover < 21.245	12	0.92	0.08*
3) Tree cover > 21.245	40	9.90	0.45
5) Community: A,B,C,D	23	4.87	0.30
7) Tree cover < 49.155	16	2.44	0.19
9) Altitude < 1603.5	9	2.00	0.33*
9) Altitude > 1603.5	7	0.00	0.00*
7) Tree cover > 49.155	7	1.71	0.57*
5) Community: E,H	17	3.88	0.64
10) Grazing < 1.005	9	2.00	0.33*
10) Grazing > 1.005	8	0.00	1.00*
2) Grazing > 1.845	183	17.03	0.10
4) Tree cover < 54.56	173	12.87	0.09
6) Mean condition < 2.585	161	10.25	0.07
8) Altitude < 1403	93	9.70	0.12
11) Tree cover < 7.13	14	2.86	0.29*
11) Tree cover > 7.13	79	6.38	0.09*
8) Altitude > 1403	68	0.00	0.00*
6) Mean condition > 2.585	12	2.25	0.25*
4) Tree cover > 54.56	10	2.50	0.50*

3.3.3 *Minimum adequate model for bird presence*

The generalized linear mixed model with the lowest AIC was fit using the binomial family with the "logit" link function using the "laplace" method. The formula of the MAM is:

Presence ~ Mean condition + Tree cover + Mean condition : Grazing + Tree cover : Grazing + (1|Transect)

The 10 randomized datasets all produced minimum adequate models with identical parameters. The maximal model from one of the randomized datasets and the subsequent models can be seen in Appendix F. Table 14 gives the parameter values of the MAM and their variation between the 10 randomized datasets. There are no significant differences between the 10 models (one-way ANOVA, F = 0.000493, *d.f.* = 9, p>0.05), and the minimum and maximum estimates vary no more than 7.3% from the mean. This result implies that re-sampling did not significantly alter the data structure.

Table 14 Minimum adequate model for bird presence/absence. Variation between parameters for the 10 randomized datasets is shown (*** = p<0.001, ** = p<0.01, * = p<0.05).

Parameter	Mean	Minimum	Maximum	Std. error
Intercept	-2.90 ***	-3.00	-2.81	0.0215
Mean condition	-2.53 **	-2.65	-2.41	0.0253
Tree cover	0.199 ***	0.193	0.208	0.00152
Mean condition : Grazing	0.769 **	0.713	0.818	0.0124
Tree cover : Grazing	-0.0522 ***	-0.0553	-0.0491	0.000583
Variance of Transect	5e-10	5e-10	5e-10	0
Model deviance	182.0	174.5	188.4	1.40

Hypothesis ii, that no factors significantly explain any variation in francolin presence/absence, is rejected. The binomial minimum adequate model for francolin presence retains two main predictors: Mean condition of juniper (negative) and total percentage tree cover (positive). Therefore, hypothesis iii, that there is no significant correlation between francolin presence/absence and juniper health, is also rejected. Two interactions are retained in the MAM – grazing : mean condition and grazing : tree cover. By taking the averages of high and low mean condition/tree cover at high and low grazing intensities, it is evident that in both interaction terms retained in the MAM, grazing affects the variables of mean juniper condition and tree cover by lowering bird presence in areas of high grazing (Figure 20, red lines), and increasing bird presence in areas of low grazing (Figure 20, blue lines). The effect of grazing is mediated through the variables of juniper condition and tree cover – grazing is not a significant main effect on its own. The nature of the grazing : mean condition interaction is that the effect of grazing is significantly higher where mean juniper condition is low. The grazing : tree cover interaction is essentially a mirror image of the first interaction – the effect of grazing is more pronounced in areas of high tree cover. Areas of high tree cover and low juniper condition are likely to be the same areas, as they have a very similar average bird presence (shown by the values in Figure 20). Therefore, we must interpret both interactions together. In these corresponding areas of high tree cover (but with less living juniper), low grazing corresponds to a mean francolin presence of 0.26, compared with high grazing, corresponding to a mean presence of 0.13.

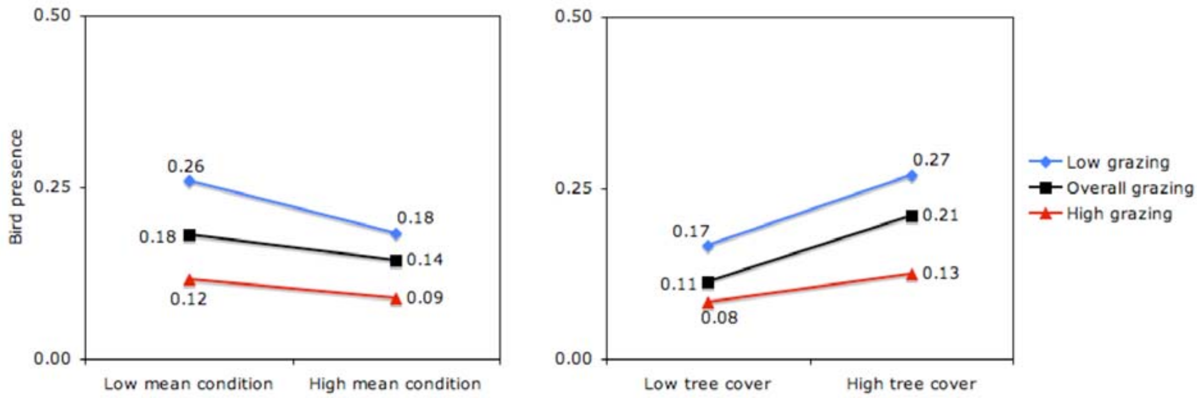

Figure 20 Mean condition : grazing and tree cover : grazing interactions in relation to bird presence. Low and high mean condition and tree cover is calculated by dividing the data set in half, with the lowest values in one dataset and highest values in the other dataset. Values shown in the plot areas are averages

Francolin presence is not shown to be significantly associated with the main effects of plant community, altitude, or grazing, and we accept the null hypothesis for these variables.

3.4 Social data

3.4.1 *Livestock differences between villages*

The interviews showed that goats, sheep and donkeys tend to graze locally in and around villages in open *Acacia* woodland, but cows require higher quality herbs, found only in the forest. The effects of non-cattle livestock on the forest are therefore probably insignificant in comparison to cows, and non-cattle livestock are therefore left out of the analysis. However, camels were also encountered in the forest, but in low numbers. They may be potentially important as their numbers are unknown and they may graze on junipers. Some families were documented to have a few camels, but as with goats, sheep and donkeys, people generally didn't know exactly how many they own – villagers could only give accurate numbers for their cows. In times of drought, villagers usually take most of their animals 60 miles to the frontier with Ethiopia in the wet season where pastures are richer, to maintain the health of their herds.

Figure 21 extrapolates the number of cows per household to each village based on their population. Tikito village has the most cows (but the largest variation in cow numbers between households). Day and Oum-desaido have approximately equal numbers of cows, while Goub and Hamboka have the fewest. The total number of cows grazing in the forest is estimated to be between 1156 and 2411. Of the total estimated 1700 cows grazing in the Garab and Barabarre regions, 70% utilise Garab and 30% utilise Barabarre (Figure 22). Combining the empirical grazing data from quadrats gives a mean grazing intensity of 3.68 for Garab and 1.90 for Barabarre, on a scale of 0 to 4, which is a ratio of approximately 3:1, and therefore very similar to the data gathered from interviews. This cross-checking supports both the field method by which grazing intensity was determined (number of piles of droppings per quadrat), and the data collected through interviews.

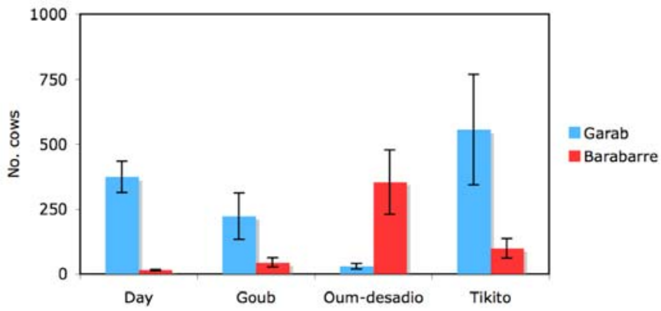

Figure 21 Number of cows per village in the two main grazing regions extrapolated from household numbers.

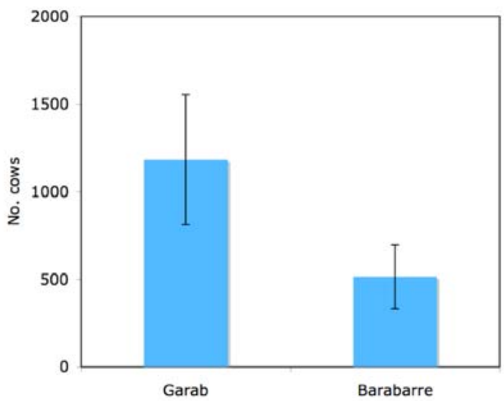

Figure 22 Estimated total number of cows grazing in the two main pasture regions, calculated from combining data from number of cows per household and their grazing preference.

A general log-linear model revealed that the only significant interaction between livestock variables and village is that of grazing region, highlighted in Figure 21. This disproves hypothesis v), that villages show no significant difference in forest usage. Oum-desaido residents show a significant difference in their choice of grazing region (Barabarre), in comparison to the other three villages that all prefer the Garab for grazing (analysis of deviance Chi-test, *d.f.* = 3, $p<0.001$). The GLM showed no other significant interactions with village or any higher-order interactions (Figure 23). Hamboka village was left out of the analysis as their cows graze locally and not in the forest (A. Dabaleh, chief of the province of Day, pers. comm.).

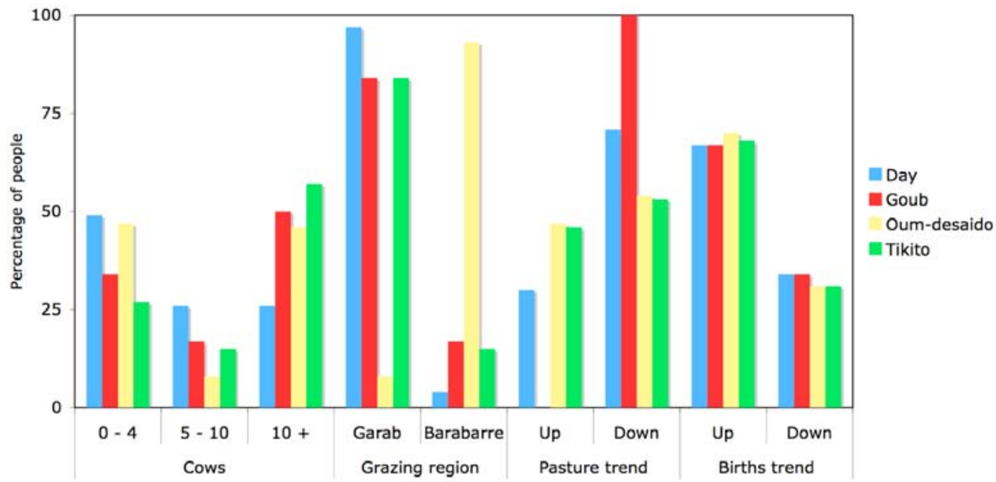

Figure 23 Trends in livestock and grazing between four villages.

About 70% of people in all villages thought that there had been more births in livestock in recent years, and the majority of people also felt that pasture availability had decreased (Figure 23). There are no clear differences in the numbers of cows that households own between villages, but there may be a divide between those households with less than 5 cows and those with more than 10.

By combining the interview responses from all villages, one-way ANOVAs did not show any significant correlations between number of cows in the household and grazing region ($F = 0.36$, *d.f.* = 2, $p = 0.70$), pasture trend ($F = 1.63$, *d.f.* = 1, $p = 0.21$) or trend in births ($F = 3.16$, *d.f.* = 1, $p = 0.08$). There is therefore no evidence that people with more cows graze in particular areas or have had higher livestock productivity. Even people with fewer cows have seen more births in their herd recently, suggesting that herd size is not necessarily related to the productivity of cattle in the last few years in the Day province.

3.4.2 *Francolin sightings by villagers*

A general log-linear model shows that there is a strong significant interaction between frequency of sighting and region (analysis of deviance Chi-test, *d.f.* = 6, $p<0.001$). Villagers sighted francolins most frequently in the Garab region (Figure 24). The majority of villagers further mentioned that these sightings were around the areas of the Ourano wadi. Barabarre and Adonta also had high numbers of sightings, while Hamboka had the least. A Spearman rank correlation between regions where birds are sighted most frequently and number of presences from transects is positive (r = 0.80), but not significant. This may be because there are only 2 degrees of freedom in the Spearman test (4 regions and 2 variables). However, the interview responses do correspond spatially with the empirical findings from transects (Figure 17). The regions of bird sightings differed significantly between villages, as did the frequency of sightings, and thus we reject the null hypothesis iv.

The reason for the differences in sighting region between villages is because the regions that people visit is dependent on where they are from. People from the same village are thus more likely to see birds in certain areas. For example, most birds seen in Barabarre are by Oum-desaido villagers, which is probably because Oum-desaido is the closest village to Barabarre. The fact that frequency of bird sightings differed between villages is dependent on the abundance of birds in areas where villagers of that village visit. The significant interaction here is likely to be due to the very few sightings seen by Hamboka villagers – who see birds rarely (as birds are rare in Hamboka).

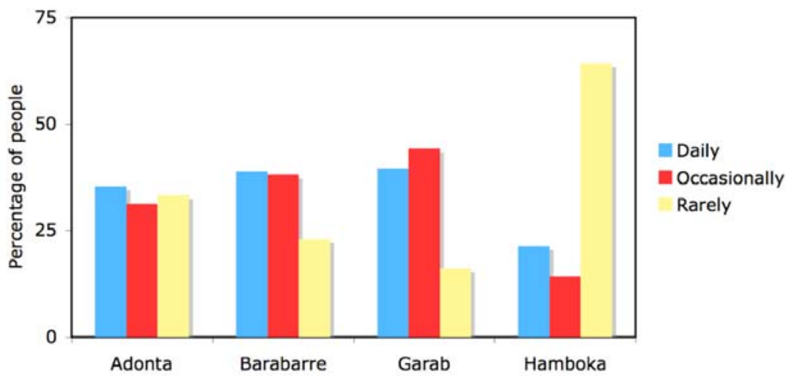

Figure 24 Total sighting frequency of francolins in four main regions of the Day Forest.

Inspection of francolin sightings by village reveals that birds in Adonta and Garab are mostly seen by Day and Goub villagers and residents of Tikito see birds mostly in Barabarre and Garab. A general log-linear model explains that there are significant interactions between village and sighting region, and village and frequency of sighting. There is also a significant 3-way interaction between village, region and frequency of sighting (analysis of deviance Chi-test, *d.f.* = 24, $p<0.001$). The 3-way interaction implies that villages differ not only in where they see francolins but also in how frequently they see them, and that there is evidence of a relationship between frequency and region, independent of village. Frequency of bird sightings did not significantly correlate with number of cows in the household (one-way ANOVA, F = 1.01, *d.f.* = 3, $p = 0.40$).

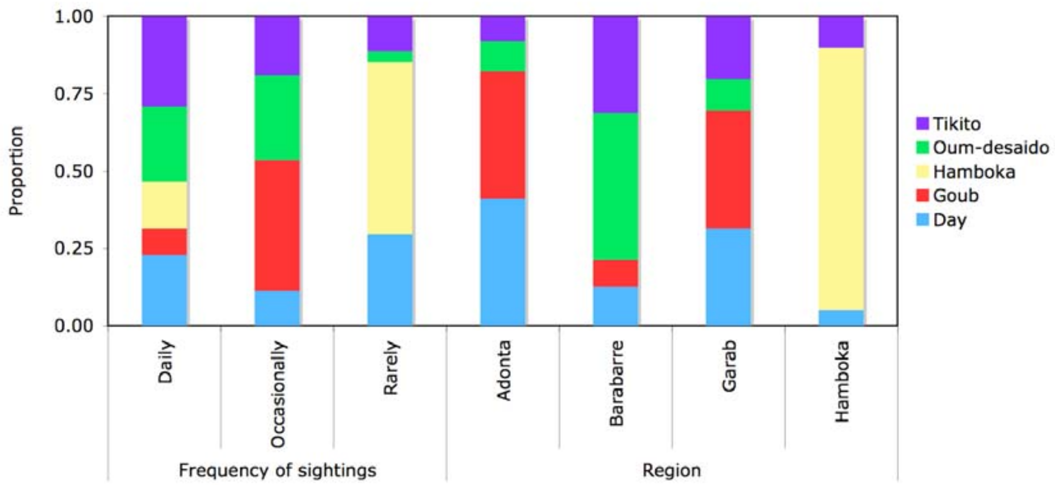

Figure 25 Francolin sightings and frequency in the four regions by village proportion.

The majority of interviewees (80%) thought that abundance of the francolin had declined. There was no significant difference in responses between villages of whether francolin abundance had gone up or down ($\chi^2 = 4.63$, *d.f.* = 4, $p>0.05$), suggesting that the decline has been felt by all villagers in the area. It was difficult to determine a time scale, but people tended to attribute the decline to the same time scale as the commencement of juniper forest death, around 1990. This corresponds with previous research in the area (Bealey et al., 2006, Magin, 2001, Welch and Welch, 1998).

3.4.3 *Attitudes towards the francolin*

Seventy-six percent of villagers thought that the francolin was important. Reasons for the francolin's importance were mainly its possible nutritive value (because bird meat is not *haraam*, thus being a permissible food for Muslims), and simply for the sake of its existence, as part of the forest's natural heritage.

Despite many people claiming that the francolin was an important potential source of food, few had heard of people that eat or hunt it today. A few older interviewees mentioned that in times past when the francolin was so abundant that it came up to the village boundaries, they would be able to trap them for food. The rarity of the francolin today means that even opportunistic catching of francolins is difficult. All villages surveyed receive food aid and most people have some source of protein. The forest, once home to the wart hog *Phacochoerus aethiopicus* (now absent) and numerous antelopes (such as the Kirk's dik dik *Madoqua kirkii* and the klipspringer *Oreotragus oreotragus somalicus*, now much rarer), now has little potential for hunting, with no identifiable buyers for bushmeat (Künzel et al., 2000).

3.4.4 *Attitudes towards the forest*

Out of the 75 people interviewed 29 were unsure of the year when the juniper forest started to die. However, Figure 26 shows the results from the 46 other interviewees. Inspection of the data confirmed that year is normally distributed. The mean and median are both 1990 with lower and upper quartiles of 1987 and 1991 respectively. A linear model showed no correlation between year of juniper death and age of interviewee ($F = 1.95$, *d.f.* $= 44$, $p = 0.17$). In addition, there was no significant association between reported year of juniper death and grazing region (one-way ANOVA, $F = 0.88$, *d.f.* $= 2$ $p = 0.42$) or village (one-way ANOVA, $F = 0.66$, *d.f.* $= 4$ $p = 0.63$).

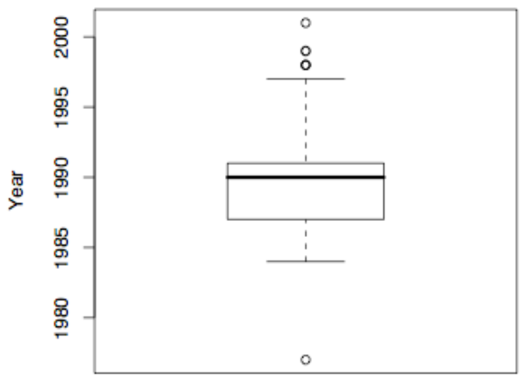

Figure 26 Year of commencement of juniper decline.

The majority of interviewees (57%) blamed drought as the main cause of forest death (Figure 27) and 17% of people were not sure why the forest had mostly died. Only 4% attributed forest death to overgrazing. This is contrary to the empirical findings and may be due to villagers protecting their interests, as grazing their livestock everyday is an important livelihood requirement. Similarly, most villagers claimed that their livestock did not eat junipers, yet some admitted that trampling of seedlings was possible – which is probably more detrimental to the forest as a whole than direct consumption. Old age was another cause raised by 12% of respondents – and a likely contributor to forest death as previously discussed. Deliberate killing by a particular French scientist, who resided in the forest for 6 months in 1981-1982 was the main reason put forward by 7% of respondents.

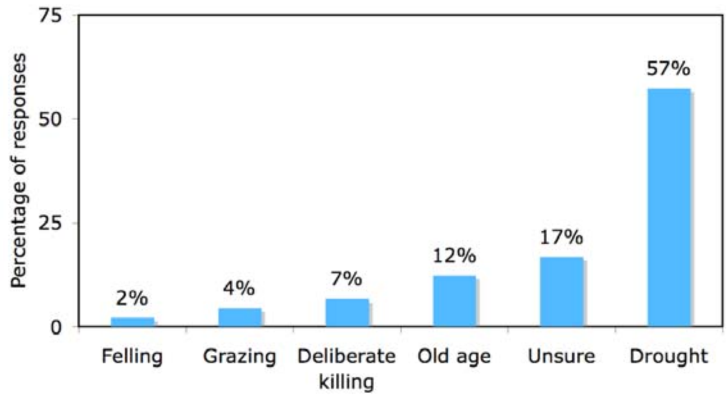

Figure 27 Reasons for tree death.

A combination of planting new juniper trees and new exclosures was the most popular management idea to aid the conservation of Day Forest (29% of responses). Almost one quarter of people said nothing could be done to save the forest, while 15% were unsure what could be done. Twenty-three percent of villagers were in favour of solely exclosures and 8% were in favour of solely planting new junipers (Figure 28). There was no significant association between the reason of forest decline and year of forest death (one-way ANOVA, $F = 1.75$, $d.f. = 4$, $p = 0.16$).

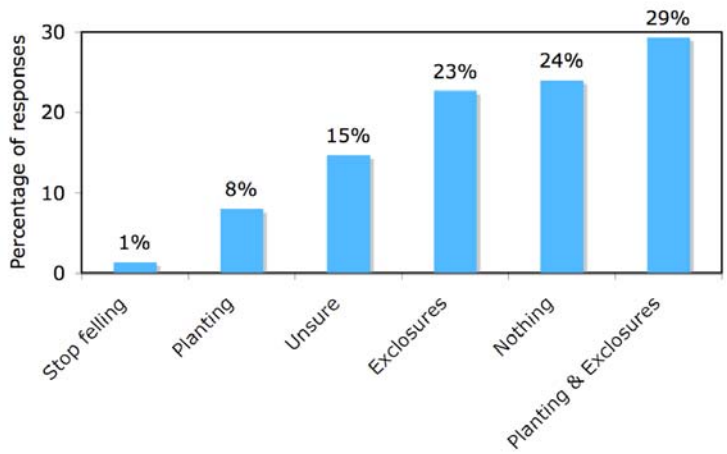

Figure 28 Forest management ideas of villagers.

4 DISCUSSION

The aim of this study were to investigate

- Which factors best predict juniper condition;
- Which factors best predict francolin presence;
- How large the francolin population is in the Forêt du Day;
- Whether the abundance of the Djibouti francolin is correlated with juniper health;
- Whether villages differ in their use of forest resources, and if associations be made between human disturbance and francolin abundance/juniper health; and
- The capacity of villagers to aid conservation of their forest.

4.1 Juniper health

4.1.1 *Density of juniper trees*

The area with the most living trees and most healthy trees is the eastern part of Barabarre. This is confirmed by observation of the satellite image. Compared to western Barabarre, an obvious divide is present, a dense woodland to the east and bare plateau to the west. However, despite a living tree density of c. 300 trees per hectare in the east (50% of total), the mean condition of these trees is just 61%, and they are matched by an equal number of dead trees per hectare. Nevertheless, other areas in the forest are significantly worse, with only 9% living juniper on the Garab plateau that has an average condition score of 44%. This demonstrates that the whole of Barabarre should be seen as a priority area for juniper, as it contains the last healthy junipers in the Day Forest. Even in western Barabarre, despite a low living tree density, the health of these trees is similar to those in the east (60%).

Differences in densities of trees in different areas is not necessarily representative of health of the area, rather we should be looking at mean tree condition, as density of trees is largely influenced by slope and topography, and possibly historical factors such as past felling (evident from large clearings in the forest). However, even though healthier trees are more reproductively active, density of trees needs to be high enough to allow successful propagation and recruitment of junipers, which are dioecious.

4.1.2 *Condition of junipers*

The minimum adequate model confirms that juniper condition increases with altitude. However, there appears to be a critical altitude of 1300 m, below which there are no living junipers. This phenomenon has been documented in *Juniperus excelsa polycarpos* in the northern mountains of Oman and in *Juniperus procera* in the Raydah Reserve in south-western Saudi Arabia (Fisher and Gardner, 1995, Fisher, 1997). To discuss possible reasons for this altitudinal gradient in tree condition, we must investigate the interactions retained in the MAM.

Figure 15 illustrates that low and high grazing levels affect juniper condition differently at different altitudes. Trees are on average 25% healthier at a given altitude in areas of low grazing, compared to those with high grazing. It thus appears that grazing intensity is negatively affecting junipers in such a way that trees of the same health but at differing grazing pressures differ in altitudinal range by 200 m, on average. Grazing may be preventing healthier trees from growing at lower altitudes. However, grazing does not correlate significantly with altitude (Pearson's $r = 0.08$, $d.f. = 328$, $p = 0.17$), so simply assuming that animals graze more heavily at low altitudes is not a satisfactory explanation for this interaction. Instead, it appears that in areas where there is a higher dead juniper density, grazing may also be unusually high, negatively affecting recruitment. It was noted in the field that grazing was particularly high in dead juniper areas, which is not surprising, given that dying trees allow sunlight to reach the forest floor, increasing herb and grass cover, thus increasing pasture quality. As areas open up, the increased herb cover available brings more animals to the site and could further inhibit generation, by positive feedback. This is a cause of concern for the future of the juniper woodland, especially because dying trees are found in the same areas as the remaining living trees (Pearson's $r = 0.54$, $d.f. = 328$, $p < 0.001$).

In the case of *J. procera* in Saudi Arabia, altitude is also the most influential variable explaining variation in condition of juniper trees, but hypotheses for juniper decline in Saudi Arabia also include overgrazing by domestic livestock, which can alter the vegetation structure, causing woodland declines at lower altitudes to be more pronounced through effects on microclimate (Fisher, 1997). This is a positive feedback effect, and heavily grazed areas may have less plant biomass and therefore less moisture. This explanation is supported by the strong evidence for an altitudinal gradient in juniper health, seen in both my study and others in the Arabian Peninsula (Blot, 1994, Blot and Hajar, 1994, Fisher, 1997, Fisher and Gardner, 1995, Gardner and Fisher, 1994, Gardner and Fisher, 1996). Not only are higher altitudes cooler and wetter, but they are further away from villages (and therefore people and animals) and tend to have a more diverse topography.

We can look into the effect of topography further, as a grazing : slope interaction was also retained in the MAM (Figure 16). At high levels of grazing, slope is more important for juniper health than in areas of low grazing. We can infer from this that where grazing is high, junipers survive better if they are on steeper slopes, because these are more difficult for livestock to reach. This is supported by the fact that grazing is significantly and negatively correlated with slope (Pearson's r = -0.45, *d.f.* = 328, p<0.001). However, at low grazing levels, there is little difference in condition of junipers on slopes of differing incline, suggesting that slope incline in the absence of grazing is not related to juniper health. Where grazing is high, steeper slopes can aid juniper recruitment and provide shade for young trees. Slopes are also not uniformly exposed to the sun as are plateaus, and thus are cooler at different times of the day.

In this study, aspect did not explain any significant variation in the MAM, but aspect did correlate significantly with slope as we have discussed earlier. One would expect that north-facing slopes would have a higher average juniper condition than south-facing slopes, as they are cooler (because Djibouti is in the northern hemisphere). The lack of correlation between aspect and juniper health in this study may simply be because the juniper forest has been disturbed so much that any possible correlation has been masked by other variables, such as grazing, that have a much bigger influence.

Altitude is the main effect in the MAM, suggesting that tree condition may be affected by factors that correlate with altitude, such as temperature and moisture. The fate of this woodland is very similar to that of the close-by Gacaan Libaax highlands of Somalia, which reach a similar maximum altitude of 1718 m, and contain a *J. procera* forest, once covering its entire range but now restricted to a small area at the highest altitudes and steepest slopes, in the remaining 'mist' forest (Miskell, 2000). Fruiticose lichens of the genus *Usnea* hanging on juniper branches clearly increase in abundance with altitude in Gacaan Libaax, as does juniper health – a clear demonstration of the effects of a cloud/mist forest climate. The same phenomenon occurs in Saudi Arabia (Fisher, 1997), and has also been noted in this study, in the Forêt du Day. Just as desiccation and grazing have negatively affected the Gacaan Libaax highland ecosystem, in Djibouti, the recent droughts are likely to have contributed to the decline in the juniper forest, with grazing exacerbating the effect. Those trees at higher altitudes would have been less exposed by drought, as cloud and fog often engulfs the peaks for much of the time (pers. obs. supported by Gardner and Fisher (1996)). With droughts becoming more frequent (USAID, 2007a), this will no doubt put more pressure on the woodland. Even trees at a higher altitude will be affected as these are already dying (despite being healthier on average).

J. procera is a long-lived tree and should be able to withstand periodic droughts (A. Farjon, Chairman, IUCN Conifer Specialist Group, pers. comm.). The fact that trees are dying may therefore be due to their old age, with little or no recruitment in recent years. If this were the case, then we still need to find out what has been inhibiting recruitment. Pathogens could be one cause, negatively affecting reproduction and decreasing tree health, but no obvious signs were noted in study. The pattern in tree density shows that the majority of trees are dead at lower altitudes and about half are dead in higher altitudes. Even if pathogens were the cause, an altitudinal gradient is still dominating. Likewise, if old age was the main cause of death, an explanation as to why a higher proportion of trees are dying at lower altitudes is still missing. As we have seen, grazing does not significantly correlate with altitude, but it may have in the past, before areas of lower altitude were exhausted of sufficient pasture. This may be a reason why we see the current trend today. Intensive low-altitude grazing in the past could have inhibited further recruitment of junipers at these altitudes, which would explain why at low altitude, the dead : alive juniper ratio is much higher than at high altitude, which could have been affected by grazing more recently. This hypothesis could be tested by aging the junipers at different altitudes. Taking height as a proxy for age, mean height did correlate significantly with altitude (Pearson's $r = -0.47$, $d.f. = 164$, $p<0.001$), but whether this is due to age or environmental factors is unknown. Unfortunately, the age of junipers is difficult to estimate by proxies such as height and diameter at breast height, and is best calculated from tree ring dendrochronology (Fisher, 1994, Cook and Kairiukstis, 1990), which was outside the scope of this study. The old-age hypothesis could be tested using this technique in future research. Exclosure studies could also be used to test whether recruitment is affected by more by old age or grazing.

Periodical drought alone may not be causing juniper decline, but in this part of Africa, it is accepted that the climate is changing, with the average temperature increasing (Solomon et al., 2007). A continued long-term increase in temperature and aridity may be a major cause of juniper death, and would also explain the strong altitudinal gradient. Grazing, which causes trampling of seedlings, will certainly exacerbate this effect at the lower altitudes where it is generally hotter and drier. However, in Oman, grazing plays a minimal role in the ecosystem and yet tree condition is strongly correlated with altitude (Gardner and Fisher, 1996). If climate change is driving juniper death, the future fate of the Day Forest is likely to be unavoidable, as compared with the global distribution of *J. procera*, this population is already occupying a low altitudinal range, with the highest peak at only c. 1750 m. Even at this peak, 50% of junipers are dead.

The unexplained residual deviance in the MAM and scatter in the graphs could be explained by an unmeasured factor. This could be tree age, but also aspects of direct human disturbance and water stress. Trees in and near wadis were observed to be much healthier in the field, even at low altitude areas. As discussed earlier, hydrology may well play a role in juniper health (Fisher and Gardner, 1995), which has not been measured in this study.

4.2 Francolin abundance

4.2.1 *Size of francolin population*

The DISTANCE model estimated a bird density of 90 francolins per sq. km, with upper and lower 95% confidence intervals of 51 and 157 birds per sq. km, respectively. Extrapolating to 7.5 km^2, the area of the study site (of which 86% was theoretically covered by the transects), the estimated francolin population in the Forêt du Day is **672 individuals** with a 95% confidence interval of **383 – 1179 individuals**. The coefficient of variation is high (28%) and results in this large confidence interval. This is not surprising given that the population estimate is based on just 54 observations. The estimated population size should therefore be treated with caution, but this is the first estimate using standard survey methodology. A more thorough, long term study is required to give a confident population estimate. Bealey et al. (2006) estimated the population size to be between 612 and 723 individuals for the entire 70 km^2 of the Goda Massif mountain range, but this estimate was not calculated using DISTANCE and covered a linear 40 km long belt of area across the central Goda Massif region. The population estimate in this report is not comparable with that estimate, due to the different methods used in reaching the final values.

Figure 17 shows that francolins were not distributed uniformly across the study area, but were found in patches. The DISTANCE model does not take into account bird behaviour, such as territoriality (Buckland et al., 2001). Even though a population density estimate has been calculated, this is an average value and local population densities will vary greatly depending on the suitability of the habitat.

It must be noted that although every effort was made not to count birds twice within a transect, on different days birds would have moved, and with transects in close proximity to one another in such an intensive study as this, we cannot rule out the possibility of counting clusters more than once. This may cause overestimation of the population size, as observations may not always be independent. The DISTANCE model assumes that distances of birds and angles were accurately measured. In the field, despite periodic calibration of estimated visual distances, it was not possible to test whether the distances and angles of audible observations (bird calls) were accurately estimated. This reduces the confidence in the final population estimate. Francolins may have also not been detected at their initial location. As shy and elusive birds, many were observed by flushing them. This indicates that they may have already moved a short distance away on approach of the observer. This bias would also affect the population estimate, but inspection of the histogram in Figure 18 does not provide evidence for this phenomenon. Instead, numbers of birds counted falls steeply after 25 m from the transect line. With an effective strip width of 39 m (Table 12) the probability of finding francolins at long distances is low. Although observations were truncated to 150 m either side of the transect in the field, this value is likely to be too high. More importantly, different habitats and topographies (e.g. wadis and open woodland) will have different maximum possible detection distances. Unfortunately, in this study, further truncation of bird observations will not provide more reliable population estimates due to the resulting small number of observations retained in the model. Future research should use a lower truncation distance to give a better estimate. The probability detection function in this study is likely to cause overestimation of population size due to the large 300 m strip width.

For the reasons described above, it is suggested that the total francolin population in the Forêt du Day is in the lower half of the confidence interval – between **383 and 672 individuals**. Because of possible inaccuracies in bird detection and differing detection distances, a precautionary principle should be taken when giving estimates. We cannot give an estimate of the francolin population for the whole Goda region, as details of suitable habitat are unknown. However, previous work has found that bird families are only sporadically found in regions other than the forest (Bealey et al., 2006), and I therefore suggest that the Day forest is the bird's stronghold, as it is the only area in the region with a large area of continuous habitat.

4.2.2 *Predictors of francolin presence*

The MAM for bird presence indicates that francolin presence is higher in areas of low juniper condition but high total tree cover. In fact, francolins seem to prefer high tree cover, irrespective of whether it includes juniper. Shade therefore, may be more important for francolins than juniper health, which is reflective of the francolins past habitat: a closed-canopy forest. Low tree health has been linked to other gamebird species that can survive in degraded habitat, such as the blood pheasant, *Ithaginis cruentus,* in China (Chen-xi et al., 2000). The blood pheasant is often found in areas of secondary forest, where deciduous trees have replaced the original coniferous forests. Like the blood pheasant, the Djibouti francolin may be finding suitable habitat in degraded areas. We cannot know whether junipers are important for francolins or not, biologically. Their death could be a causative factor for francolin decline, but this study does not provide any evidence that healthy juniper is particularly important for francolin survival in the months of May and June. With little known about the Djibouti francolin's biology, we do not know whether healthier juniper habitat may be favoured at other times, for example in the breeding season.

How can francolin presence be positively correlated with tree cover whilst being negatively correlated with juniper condition? The answer is that francolins must be finding areas with high total tree cover that do not have juniper of a high condition, thus other tree species are providing the required shade. The species which has a percentage cover that correlates highest with tree cover and also forms the majority of total tree cover is the commonest tree in the region: box, *Buxus hildebrandtii*. Box percentage cover is significantly and negatively associated with juniper condition (Pearson's $r = -0.34$, *d.f.* = 272, $p<0.001$). Since the death of the forest, it is very likely that box trees have replaced the juniper in some areas. Although plant community did not feature in the MAM, the TWINSPAN results show that c. 49% of the forest area is dominated by box, which is present as an indicator in 4 of the 8 plant communities (Table 5). 70 % of the francolin observations were in these box-dominated areas, further emphasising the potential importance of this tree. Box is a much faster growing tree than juniper and therefore it is feasible that a substantial change in plant community composition has taken place following the decline in juniper. Like the Djibouti francolin, the handsome francolin, *Francolinus nobilis* in western Uganda prefers dense patches of forest over open areas, highlighting the importance of tree cover (Fuller and Ssemmanda, 2005).

Factors measured in the Djibouti study that significantly correlate with tree cover are slope angle (Pearson's $r = 0.30$, *d.f.* = 328, $p<0.001$) and herb cover (Pearson's $r = 0.32$, *d.f.* = 328, $p<0.001$). These may also be linked with francolin presence. Herbs and steep slopes both provide shelter, but herbs also provide forage. However, we can only speculate the importance of these factors, as they have not been proven to be associated with francolin presence directly through modelling.

Interpretation of the MAM shows that in areas of high tree cover, but less living juniper, francolin presence is higher in areas of low grazing than areas of high grazing. Why should grazing alter francolin presence in these areas more so than in more open woodland with healthier juniper? One possibility is that in open woodland (low tree cover), forage for the francolins may be of a better quality as more herbs are present, and grazing has a smaller effect on their abundance because forage/shelter is sufficient for both livestock and animals. In areas with denser trees, competition between animals and francolins for forage is fiercer as under-storey herbs are less abundant. Nevertheless, the fact that francolins appear to be favouring areas with high tree cover, and that in these areas the effect of grazing is more pronounced, is a major cause for concern because grazing intensity is generally high in whole region. High grazing pressure may put stress on the francolin population.

An alternative hypothesis is that, because grazing is significantly negatively correlated with tree cover (Pearson's $r = -0.33$, $d.f. = 328$, $p<0.001$), francolins may be escaping livestock to areas which have a denser forest canopy, where disturbance by livestock is less, possibly resulting in higher quality of forage or shelter. The effects of grazing in these sheltered areas are high because when livestock are present, bird presence is significantly less.

Evidence of possible edge-effects are apparent in the results. Figure 17 shows that francolins were more abundant in the east, in the heart of the forest habitat, than in the west. Their absence from the western edge of the forest is not surprising given that this is closest to the villages, with many clearings. Edge-effects for other ground-dwelling birds has already been documented in montane forests, for example in the case of the chestnut-bellied hill-partridge, *Arborophila javanica* (Nijman, 2003), which prefers the forest interior over edges.

It should be noted that the performance of the GLM is limited by the accuracy of the data. Even though transect number showed no bias in francolin presence, the placement of transects across the study area may do. This is because not all transects had randomized start points, as some areas were far to reach and the timing of all transects had to be within the same daily time interval. Topography particularly limited the ability to randomise transects over the study area. For example, some transects had to be in wadis or along ridges. Different vantage points have different detection distances and this would have altered the probability of finding francolins. In future modelling, spatial autocorrelation of data points should be conducted by including random effects for different topography types, as well as geographic coordinates. This may help tease out further bias, but in this situation, it is often difficult to completely eliminate bias as detection distances will always vary in such a diverse and patchy, mountainous habitat.

The study has not taken into account whether francolins move between different areas at different times of the day, month, or season, and this limits what we can infer from the model. Residual deviance is present in the model, and there are likely to be unmeasured factors that are causing this. Such variables may include human disturbance, and presence of key plant species providing nutritious food. Detailed observational studies would help discover such variables, if any.

Nonetheless, in the field it was noted that birds were generally present in the same areas throughout the day. During the study period (the duration of May and most of June) bird locations were predictable when walking around the entire study site, often with birds encountered in the exact same location on multiple occasions.

Because the effective strip width was 39 m (discussed earlier), it is recommended that future research aimed at obtaining an accurate population estimate conducts more transects, in closer proximity to one another, in order to sample a larger proportion of the area. Transects should also be repeated at different times of the day and seasons to pick out any daily or seasonal changes in francolin density. Future research could also incorporate long-term radio tracking to examine francolin habitat preference.

4.2.3 *Francolin sightings by villagers*

The results from the section of interviews relating to francolin sightings confirms the empirical data and thus provides support for my field methods, suggesting that the biases introduced in the field have not significantly affected the quantitative results. Furthermore, no villagers mentioned that birds move between different areas (although this was not one of the questions). The confident answers given by interviewees suggest that even though seasonal or daily movements of francolins may occur around the area, francolins are still seen in the regions identified both by the transects and by interviews for most of the year, as all villagers who visit the forest do so all year round.

4.3 Anthropogenic influences

4.3.1 *Livestock and grazing intensity*

The area where junipers are healthiest, in eastern Barabarre, corresponds to a low grazing score. Botanists have observed cattle both eating and trampling *J. procera* seedlings in the Gacaan Libaax highlands of Ethiopia (Miskell, 2000), and Djibouti's juniper forest faces a similar threat. The fact that grazing intensity is reduced as distance from the village increases suggests that cattle currently find sufficient pasture on western Barabarre. However, if droughts become a more frequent phenomenon, cattle will need to travel further to find sufficient forage. This endangers the future of the Barabarre mountain, as the main consensus in the interviews was that pasture quality had decreased over the years. Villagers take their cattle to the Ethiopian frontier in times of severe drought, but Ethiopian grasslands are also experiencing climatic changes and failed rains – Ethiopia's pastoral situation has been listed as 'Emergency' status since 2004 by USAID's Famine Early Warning Systems Network (USAID, 2007b). Djibouti's situation is less severe (current status 'Warning') but may reach pastoral crisis if rains fail this year (USAID, 2007a).

Seventy percent of villagers claimed that productivity of their livestock had increased recently. Most attributed this increase to recent rains in 2006. Despite a long-term increase in aridity in the region (corresponding with a reported decrease in pasture quality), a temporary flush of good herb and grass cover would have followed rainfall, allowing a high proportion of cattle to reproduce. This is a typical occurrence in arid regions such as Djibouti, and is a driver of the nomadic lifestyle (Ezaza, 1992). In the past, Djiboutian herdsmen followed the rains with their livestock, leaving areas of exhausted pasture behind (Blench and Marriage, 1999). People have now become sedentary in the Day province, but have they retained their nomadic way of thinking? With increased probability of desertification in the region (Parry et al., 2007), grazing will become more unsustainable if the cattle remain in one place. Not only will this be detrimental to the Forêt du Day ecosystem, but to people's livelihoods, as cattle are a source of milk and other dairy products, and their calves a source of protein and income.

4.3.2 *Capacity of villagers for community conservation*

Some villagers attributed the death of the juniper forest to the scientist who studied the forest ecosystem in the 1980s, seen taking cores of juniper trees. Having a scapegoat on which to blame the forest's death could be easier for those who don't want to be personally blamed. The rumours created by this issue may have given villagers a bad impression of foreign researchers in general, and thus could have affected some of the responses given in the interviews that I collected.

The fact that most people thought drought was the main reason for forest death shows that most villagers show some understanding of a possible reason for the decline of the forest. Similarly, almost everyone who thought that the francolin population has declined attributed this to drought. However, 17% were unsure of the causes of forest death. A conservation action plan would need to tackle overgrazing, but with only 4% of villagers blaming grazing, this could be problematic for creation of the action plan. Any community-based conservation programme will need to address the concerns of the villagers with respect to the importance of grazing their livestock, and will need to educate villagers by drawing attention to the possible effects of livestock on the forest.

This could be achieved by demonstrating the effect of exclosures on forest and plant regeneration. Two experimental exclosures exist in the forest, built with stone walls and deadwood to keep out cattle. Built by the villagers themselves based on an idea by Djibouti Nature, a local NGO, they clearly demonstrate the effect of grazing on the forest (Figure 29). There is good juniper regeneration and thick herb and grass cover in the exclosures, despite being rather small (1 - 2 ha at most) and only in their second year. It is no doubt that these exclosures have already given the villagers ideas about how to conserve their forest – 52% of interviewees thought that building exclosures would help regenerate the forest. Therefore, even though villagers perhaps did not want to admit that grazing was affecting the forest, they seem to understand the effects of grazing to a certain extent. A further 37% mentioned that planting new juniper trees would be beneficial, but many raised the issue of water shortages and the difficulty of helping the forest without adequate natural water resources. Even though villagers receive sufficient piped water from wells via pumps, they did not seem to favour using this resource for watering trees – probably due to its limited availability.

The ideas for forest management provided by villagers are reassuring for community-based conservation. However, one quarter of interviewees exclaimed that nothing could be done to save the forest. When asked why, it was not that the villagers did not know how to help conserve the forest (it is easier to educate those people who are unsure how they can help), but that the forest's fate was in the hands of God and no actions on the ground could improve the situation. This attitude shared by a large proportion of residents is a set-back for community-based conservation programmes, and will need to be addressed as will-power is a necessary driving factor for successful conservation.

Figure 29 Photo of an exclosure in the Day Forest demonstrating the effect of grazing. Photo © Zomo S Y Fisher 2007.

It was good practice to allow villagers to ask the interviewer questions and raise any concerns at the end of interview. Surprisingly, most villagers (of all ages) exclaimed that their livestock had suffered not only from drought but also from the leopard. Many were concerned that the NGOs involved in gaining information from villagers about the Djibouti francolin were not considering the needs of the people, notably the health of their herds. Livestock being killed by leopards on the scale proposed by villagers seems unlikely given that no leopard tracks or faeces were encountered during the field work and leopards have not been seen in the forest since the 1980s (H. Rayaleh, Ministry for the Environment, Djibouti, pers. comm.). However, the story of a leopard encountered near a school in the region that badly injured a villager over 20 years ago seemed to crop up on many occasions. This story may have been retained and passed down to the next generation in subsequent years, since the threat is still seen as imminent. It is crucial that future conservation programmes incorporate the perceived needs of the villagers, including livestock security, in order to obtain their expertise and man-power for management of the forest. Cultural knowledge of the region is invaluable and it is hoped that efforts are made to obtain more of this knowledge before implementation of conservation actions on the ground. More importantly, conservation plans must be ecosystem-oriented (including the people in the ecosystem) rather than francolin-oriented, which, based on my 2 months of experience in the area, would be badly received. Scientifically-speaking, the factors correlated with francolin abundance and juniper health are not identical, further advocating an ecosystem-approach to conservation of the Forêt du Day; protection must be sufficient for both francolins and the juniper forest. An action plan that builds on these issues is proposed in Appendix G.

5 CONCLUSION

5.1 Main findings

The status of the remaining *Juniperus procera* forest in the Forêt du Day is alarming. Juniper tree condition is significantly predicted by altitude, but even the healthiest forest is 50% dead. The altitudinal decline is similar to that in other *Juniperus* forests in the region, and climate change is likely to be the driving factor. However, grazing pressure has a significant interaction with altitude and overgrazing is probably exacerbating the decline of the juniper forest. Furthermore, in areas of high grazing, steeper slopes are correlated with better juniper health. Interview data estimates that the forest started dying around 1990. Drought is the main cause highlighted by villagers.

The Djibouti francolin population is estimated between 382 and 1179 individuals in the Forêt du Day, with a global population not being much higher than this. The population size is probably at the lower end of this confidence interval as it may have been overestimated in the field. High total tree cover significantly predicts francolin presence, but juniper cover does not seem to be a particular requirement for francolins. Instead, shade and good quality herbs, associated with *Buxus hildebrandtii,* which has probably replaced a lot of the original juniper, are associated with francolin presence. In areas of high box cover, grazing may be having a greater effect on francolin abundance than in open juniper woodlands.

Anthropogenic influences on juniper health and francolin abundance are mediated through the large number of cows grazing intensively in the forest, with tree felling and hunting being of minimal concern. Villagers are concerned by drought and their livestock have suffered as a result in recent years. A conservation action plan has been proposed that aims to incorporate the livelihoods of villagers and protection of Day Forest ecosystem.

5.2 Summarizing the strengths and limitations of the study

The data collected in interviews corresponds well with empirical data on francolin density and grazing pressure in different areas. This is a major strength of the study as both types of data, social and empirical, support the study's conclusions. The study has also covered the extent of the remaining juniper forest in a systematic manner, thus strengthening the confidence of the results, as large sample sizes have been obtained. However, this study has been limited by the short time available, and thus conclusions that are drawn can only be based on this snapshot taken in time. Whilst other aims of the study have been met, models of francolin presence in particular are confounded by the season in which the study was carried out and the few numbers of bird observations noted. This limits our ability to make accurate population estimates or draw confident conclusions about what best predicts francolin presence. This issue has been partly resolved by gathering historical knowledge using interviews. Nevertheless, this study cannot discover the actual causes of francolin decline or juniper forest death, but it has inferred conclusions from correlations between variables and juniper health and francolin abundance.

The conclusions drawn regarding juniper forest health are very similar to those of other studies on juniper forests in Africa and Arabia. There are no studies on francolins in a habitat like that of the Day Forest that can be compared to my study, but similar issues have been highlighted in studies on Galliformes in forests around the world. My study, however, is unique from others in the region, in the sense that it has possibly shown non-preference of healthy juniper habitat by francolins. This finding is important given that in the past, francolins were associated with dense juniper forest.

5.3 Areas for future research

Little is known about the size and status of the francolin population in the Mabla Mountains, and this region therefore urgently requires research, especially because the population in the Day Forest is so low. However, in the Day Forest, a long-term radio-tracking study would be valuable, to understand the francolin's habitat preference. Further transects should be continually carried out all year round, to complement the radio-tracking survey but to also gain a more confident population estimate. Francolin presence data from future transects can be overlaid on data maps produced in my study, to gain a better understanding of the best predictors for francolin presence. Only a time-series analysis such as this will provide an insight into what is actually causing the francolin's decline. Further botanical surveys are also required to monitor changes in grazing pressure and juniper health, and the effects of implemented management programmes. Further recommendations for future research that include community participation are detailed in Appendix G.

5.4 Summary

This study is the first of its kind in the horn of Africa and has highlighted a unique and highly degraded ecosystem, which urgently requires international attention and national protection. This study is the first detailed quantitative assessment of plant community composition, juniper health and francolin abundance in the Forêt du Day, and has also documented livelihood data from all the villages that utilise the forest. The study therefore sets an important benchmark for future research and ongoing monitoring. The conclusions from the study highlight that conservation action is needed that incorporates not only the Djibouti francolin and juniper forest but also the livelihoods of villagers.

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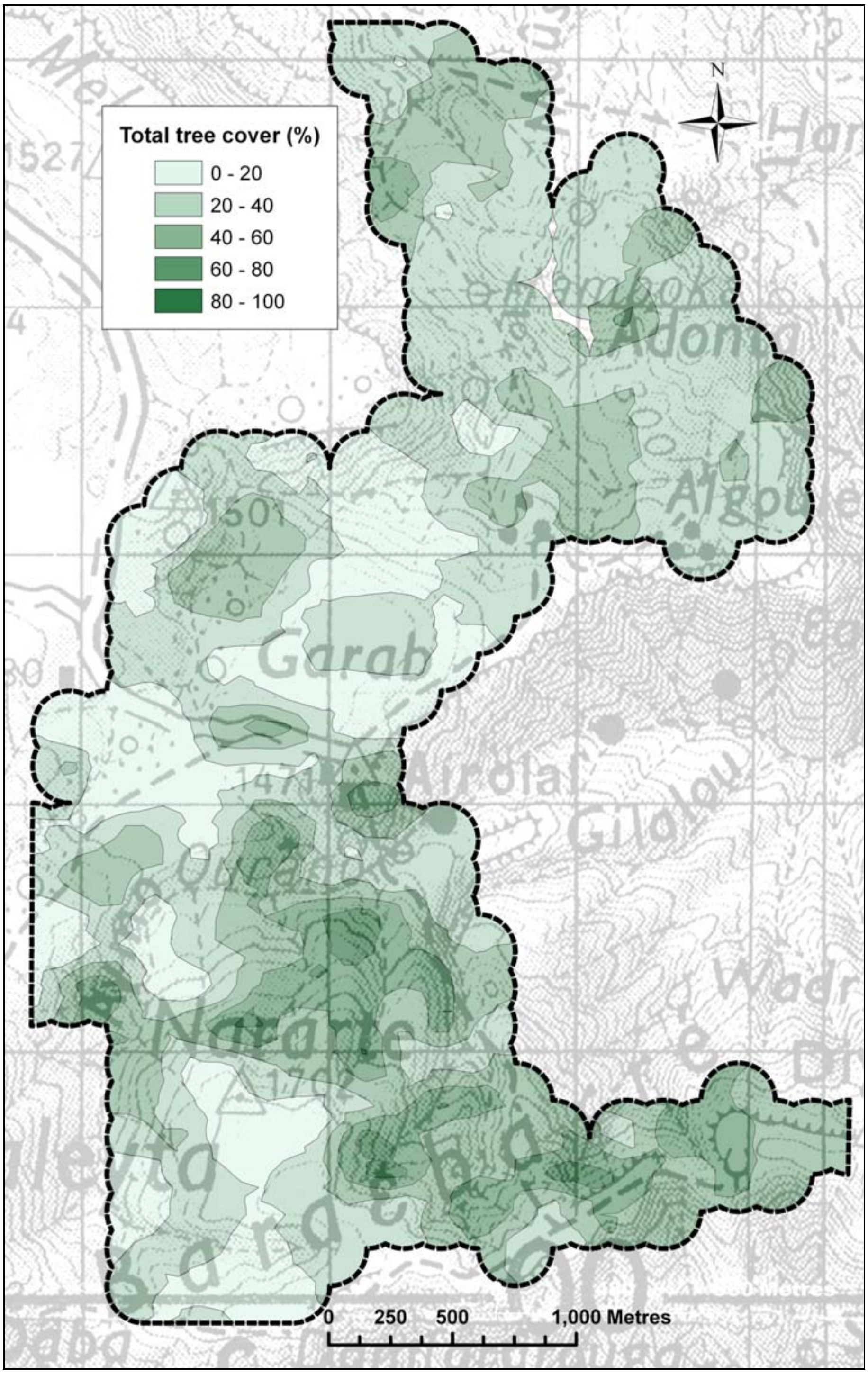
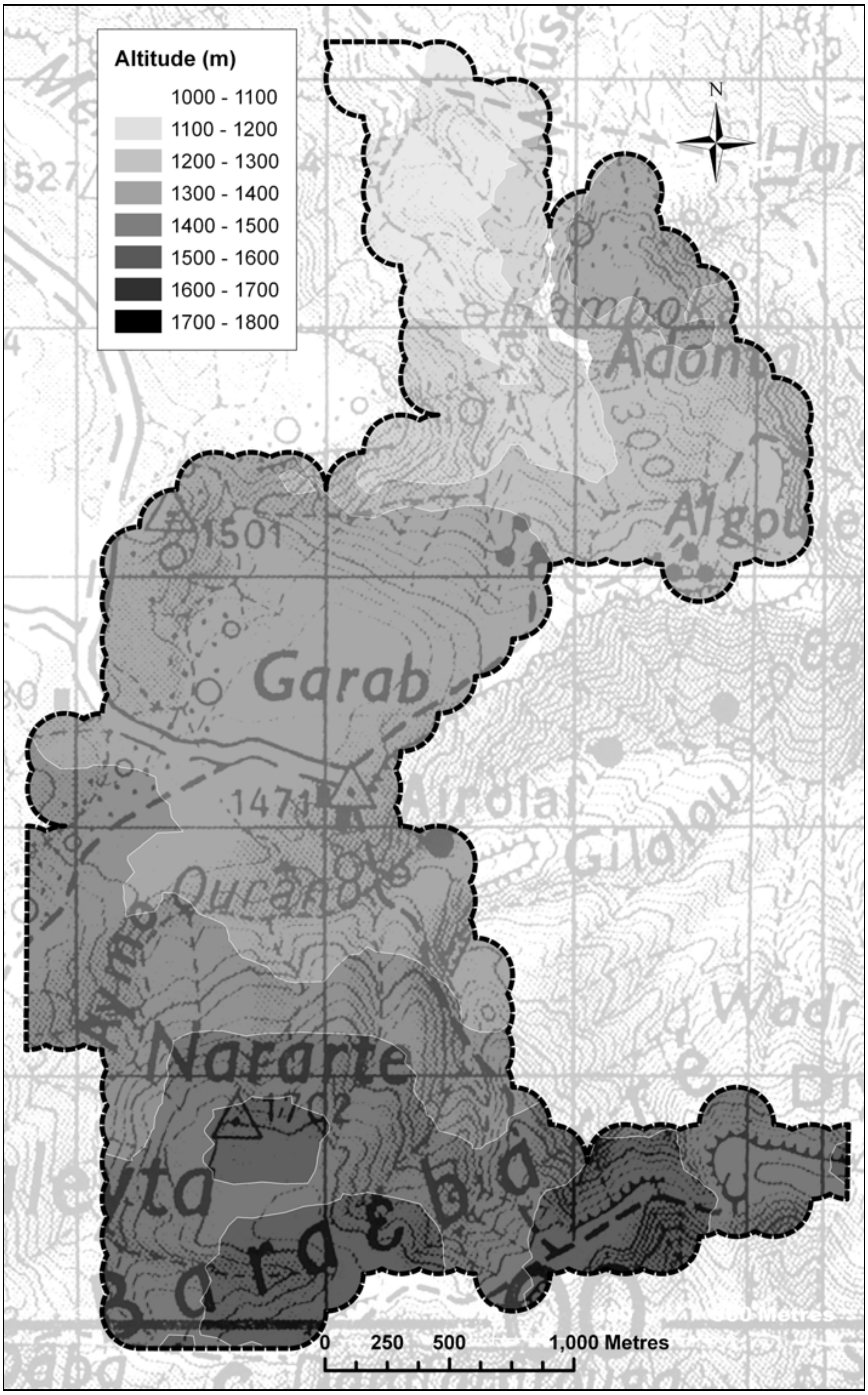
7 APPENDICES

7.1 Appendix A: Contour map of total tree cover



7.2 Appendix B: Contour map of altitude



7.3 Appendix C: Interview questionnaire

20 minutes maximum

Key: (n) = numerical data, (c) = categorical data, (f) = free speech

1 Introductory questions

1.1 Note down sex (c)

1.2 What is your job? (f)

Quell est votre travail?

1.3 How old are you? (n)

Quelle age avez-vous?

1.4 How many people in the family? (adults/children) (n)

Combien de personnes sont dans votre famille?

Combien d'adultes/enfants?

1.5 How long have you lived in this village/region? (n)

Combien de temps avez-vous vécu dans ce village/cette région?

1.6 Did you always live here or did you come from somewhere else? (c)

Avez-vous toujours vécu ici ou bien venez-vous d'ailleurs?

1.7 (If applicable) Do you think you will move away again, or stay here? (c)

Pensez-vous que vous allez rester ici ou bien déménager à nouveau?

2 Animals

2.1 How many animals do you have and how many of each (goats, sheep, etc.)? (n)

Combien d'animaux avez-vous?

Lequel de chacun?

2.2 Where do you take your animals for grazing (which region(s))? (c)

Où emmenez-vous paître (brouter) vos animaux?

Quelle(s) region(s)?

2.3 In which seasons do you take your animals for grazing? (c)

A quelle(s) saison(s) faites-vous brouter vos animaux?

2.4 Do you take the animals to different places in different seasons? Where? (c)

Emmenez-vous vos animaux (paître ou brouter) à différents endroits suivant la saison?

Où?

2.5 How often do you graze them (once a day, once a week, constantly, etc.)? (c)

A quelle fréquence les emmenez-vous brouter (une fois par jour, une fois par semaine, constamment)?

2.6 Do you think there is enough pasture? (c)

Pensez-vous qu'il y a suffisamment de champs pour vos animaux?

2.7 Do you think the amount of pasture has increased/decreased over the last few years? (c) Why? (f)

Vous pensez que la quantité de pâturage a augmenté, ou a diminué en ces dernières années?

Pourquoi?

2.8 Do you feed some animals a particular kind of food or graze them on a particular food? (c)

Nourrissez-vous certains animaux avec un type de nourriture particulier?

Quoi?

2.9 In the last few years, has the number of calves born increased/decreased/stayed the same? (c) (If applicable, why?) (f)

En ces dernières années, le nombre de met bas né a augmenté, a diminué, ou est resté les memes?

Pourquoi?

2.10 Do you have more or less, or the same number of animals than you did a year ago? (c) (If applicable) How many more/less? (n) (If applicable) Why is this? (f)

Avez-vous plus, ou moins, ou le même nombre d'animaux que l'année dernière?

Combien plus/moins?

Pourquoi?

2.11 How many of your animals do you sell each year? (n) (If applicable) Where do you sell them? (c)

Combien de vos animaux vendez-vous chaque année?

Où les vendez-vous?

2.12 How many do you eat each year? (n)

Combien d'animaux mangez-vous chaque année?

3 Forest use

3.1 How often do you visit the forest? (n)

A quelle fréquence visitez-vous la forêt?

3.1.1 During which seasons? (c)

Pendent quelles saisons?

3.2 When exactly were you last in the forest, and what were you doing there? (c)

Quand exactement étiez-vous pour la dernière fois dans la forêt, et qu'y faisiez –vous?

3.3 What do you use the forest for (firewood, hunting, grazing, recreation, etc.)? (c)

Vous vous rendez dans la forêt pour: collecter du bois, chasser, faire paître vos animaux, loisirs?

3.4 What fuel do you use for cooking (kerosene, firewood, etc.)? (c)

Quel combustible utilisez-vous pour cuisiner (kérosène, bois, etc.)?

(If they collect firewood):

3.4.1 How much per day or week? (n)

Combien prenez-vous par jour ou par semaine?

3.4.2 From which area? (c)

De quelle(s) zone?

3.4.3 From which plants or trees? (c)

De quelle(s) arbes ou plantes?

3.4.4 How far do you have to travel, in minutes, to collect firewood? (n)

Combien de temps vous déplacez-vous, en minutes, pour aller collecter du bois?

3.4.5 Is it more or less easy to collect firewood today than in the past? (c) (And if applicable, why? (f)

Est-il plus ou moins difficile de collecter du bois aujourd'hui que dans le passé?

Pourquoi?

3.5 Is there enough water available to the village? (c)

Y a-t-il assez d'eau disponible pour le village?

3.6 Has the amount of water available changed over the last few years? (c)

La quantité d'eau disponible a t'elle changé ces dernières années?

3.7 What are three most important things you get from the forest? (c)

Quelles sont les trois choses les plus importantes que vous obtenez de la forêt?

3.8 In which year did the forest start to die? (n)

En quelle année la forêt a-t-elle commencé à mourir?

4 Francolins

4.1 When exactly did you last see a francolin? (c)

Quand avez-vous vu pour la dernière fois un francolin?

4.2 What was it doing? (f)

Que faisait-il?

4.3 Which area did you see it in? (c)

Dans quelle zone l'avez-vous vue?

4.4 How often do you see them (everyday, once a week, hardly ever, etc.)? (c)

Combien de fois les voyez-vous (tous les jours, chaque par semaine, jamais?)

4.5 In which region do you see them the most? (c)

Dans quelle région (zone) en voyez-vous le plus?

4.6 How many would you say you have seen in the past year? (n)

Combien de francolins avez-vous vus au cours de la dernière année?

4.7 Do you think there are more or less of them now than in the past (c)

Pensez-vous qu'il y en a plus ou moins que dans le passé?

4.8 Do you know or have you heard of people who have caught them and sold them or their eggs, or eaten them or their eggs? (f)

Avez-vous entendu parler de gens qui les attrapent et les vendent (les oiseaux ou leurs œufs), ou qui les mangent (les oiseaux ou leurs œufs)?

4.9 (If applicable) Do people sell the birds/eggs (to others in the village, people from other villages, people from the city?) (c)

Est-ce que ces gens vendent les oiseaux/les œufs à d'autres personnes dans le village, à des habitants d'autres villages ou à des gens de la ville?

4.10 Do you know if they or their eggs are worth a lot of money? (f) (If applicable) How much? (n)

Savez-vous si les oiseaux ou leurs œufs valent beaucoup d'argent?

Combien d'argent?

4.11 Do you think the francolin is important? (c) For what reason? (f)

Pensez-vous que le francolin est important?

Pourquoi?

5 Final questions

5.1 What do you think about the condition of the forest and how it has changed? (f)

Que pensez vous de l'état général de la forêt et comment a t'il changé?

5.2 What do you think would be good ways of keeping the forest, and its resources alive? (f)

Quelles pourraient être selon vous les solutions efficaces pour garder la forêt et ses ressources en bon état?

5.3 If the forest were not here, which things would you miss the most (resources, happiness, etc.)? (c)

Si la forêt n'était plus là, qu'est-ce qui vous manquerait le plus?

7.4 Appendix D: TWINSPAN output[#]

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28 Dodo visc 1----3------------3-------------------------------------------------------3------------------------- 111

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             0000000000000000111111111111111111111111111111111111111111111111111111111111111111111111111111111111
             0000000001111110000000000000000000000000000000000000000000000000000000000000000011111111111111111111
             0111111110001111000000000000000000000011111111111111111111111111111111111111111100000000000000111111
              00111111       0001111111111111111111000000000000111111111111111111111111111111000000001111110000000
               000111          0000000000000000011000000011111000000000000000000000000000110000011101111100000

             AAAAAAAAAAAAAAAABBBBBBBBBBBBBBBBBBBBBBCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCDDDDDDDDDDDDDDDDDDDD
```

[#] Characters in bold type indicate the quadrats that belong to a given plant community.

```
             111222222222222222223331122222233222333223   111122222222          11111111111222222   1111112     1
             7890056666777778888000189999990028900058099900371122222334555778990014444667723338957713336731479 90
             9784990157345689015613419234589075275688321275890680378925712434203167345768136034803258238526881489

21 Grew vill ----------------------------------------------------------------------------------------------------  000
26 Pist falc -2-------------------------1------------------2--------------1---------------------1-------1-------3  000
 1 Juni proc 543446674366652654456555176675765456665647---------------1--11-13-1-111--11-21--1-----1---2-3--11---  0010
13 Side masc 4221-2313111122--123434-3--111-1313314353421-11111-1-12-13------11-33-1-3--2---23-21----------1----1  0010
16 Olea euro 12-31332432221244413113--323541323143-222-211111331411232---------1-------1-2---3------21--111----11  0010
40 Baby whit ---------------------------------7554-4737----------------------------------------------------------  0010
35 Eury arab 6-74425-3427424226--5637766745675777667--3-------2-------2------1-------------------3322--2-11524245  0011
 6 Tarc camp 545-4556555656646653533-433344514-55145445----------------------------------------2----3-21---------  0100
24 Meyt unda --------------------------3455522--1--5------------------------------------2------------------------  0100
30 Bauh tome --------1-------------------------------------------------------------------------------------------  0100
19 Grew eryt ----------------------------------------------------------------------------------------------------  01010
39 Psia punc 476435455756176455-3----6-773-733-2-4-44---------------------------------------1----------------2---  01010
 7 Rhus reti --------------------------------------------------------------------------------------1-------------  01011
15 Mang indi ----------------------------------------------------------------------------------------------------  01011
33 Apoc ynac ----------------------------------------------------------------------------------------------------  01011
 9 Acac etba --------------1----------------------------------------------------------------------1--------------  011
12 Acac horr ----------------------------------------------------------------1-----------------------------------  011
18 Grew velu -2-------------------------1------------------------------------------------------------------------  011
38 With somn -----13341--2-----21-1-1--2--1----2----21--------------------------2----------------221332-3-1--1---  100
44 Sola cord -----------------------------------------------------------1----------------------------------2-----  100
34 Nica phys ---------------------------------------------------------3-------------1---------------3------------  1010
36 Datu mete ----------------------------------------------------------------------------------------------------  1010
37 Calo proc ----------------------------------------------------------------------------------------------------  1010
 2 Buxu hild ---------------------------------------2--6555365663676666676776765556776756676776666745676556445555  10110
14 Term ina2 --------------------------------------------------------------------------------------3-------------  10110
22 Eucl race ----------------------------------------------------------------------------------------------------  10110
45 Rici comm -------------------------------------------------------------1-------------------------------5------  10110
 3 Ficu vast -----------------------------------------1----------1--1-----------2----1--1--2------------1------1-  10111
20 Grew bico ---------------------------------------------------------------------------------------------1------  1100
27 Tare grav ----------------------------------------------------------------------------------------------------  11010
 4 Ficu syca ----------------------------------------------------------------------------------------------------  110110
23 Comb moll ----------------------------------------------------------------------------------------------------  110110
29 Zizy spin ----------------------------------------------------------------------------------------------------  110110
31 Trem orie ----------------------------------------------------------------------------------------------------  110110
32 Drac ombe ----------------------------------------------------------------------------------------------------  110110
41 Indi coer ----------------------------------------------------------------------------------------------------  110110
42 Salv pers ----------------------------------------------------------------------------------------------------  110110
10 Acac seya ----------------------------------------------------------------------------------------------22----  110111
11 Acac asak ----------------------------------------------------------------------------------------------------  110111
43 Cari spin ----------------------------------------------------------------------------------------------------  110111
 5 Ficu cord ----------------------------------------------------------------------------------------------------  111
 8 Rhus nata ---------------------------------------------------------------------------------------------1------  111
17 Comm kua  ----------------------------------------------------------------------------------------------------  111
28 Dodo visc ---------------------------3------------------------------------------------------------------------  111

             0000000000000000000000000000000000000000001111111111111111111111111111111111111111111111111111111111
             1111111111111111111111111111111111111111110000000000000000000000000000000000000000000000000000000000
             1111111111111111111111111111111111111111110000000000000000000000000000000000000000000000000000000000
             1111111111111111111111111111111111111111110000000000000000000000000000000000000000000000000000000000
             0000000000000000000000000000000001111111110000000000000000000000000000000000000000001111111111111111
             0000000000000000000000011111111110000001110000000000000001111111111111111111111111110000000000111111

             DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
```

```
           12111  1111112                                                      1111      1             1 122 333333
           322267801233381255666667 8    111111222222233334444445566677888111612348 81   13  233466819013911112 05
           7412094390041747691236786345612357901345681289012569055896757825696204034279061893430493609151263398

21 Grew vill ---------------------------------------------------------------------------------------------------12--  000
26 Pist falc ------------1-------------------------------------------------------------------------------------------1-  000
 1 Juni proc --2--414122326-----1-----------------1-11--1-211-32----2----1---2-13114-31----1231--1---------------  0010
13 Side masc ---1-1--1---33----1------------------------------1---------------------------------1-----------------  0010
16 Olea euro --------1-1--------2-----------------------3---1-----11--------------1----------------2331-------2  0010
40 Baby whit -----------3--------------------------------------------------------------------------2----4------------  0010
35 Eury arab 32-3------------1--------2-31---4-1-11-------------1-----3-------4263554377674637775356741---------  0011
 6 Tarc camp -------1--------------------------------------------------------------------1---------------------2-  0100
24 Meyt unda ---------------------------------------------------------------------------------------------------------  0100
30 Bauh tome ---------------------------------------------------------------------------------------------------------  0100
19 Grew eryt ---------------------------------------------------------------------------------------------------1--  01010
39 Psia punc 1-777--141133--------------------------------------------------------------------------1-------------  01010
 7 Rhus reti ---------------------------------------------------------------------------------------------------------  01011
15 Mang indi ---------------------------------------------------------------------------------------------------------  01011
33 Apoc ynac ---------------------------------------------------------------------------------------------------------  01011
 9 Acac etba -------------------------------------------------------1---------------2-------------4--------23--  011
12 Acac horr --4-------------------------------------------------------3--------1--------------------------  011
18 Grew velu --2-1---1------------------------------------------------------------------------------------------------  011
38 With somn --43436344523-5666576666555531-51-321433643323141333-2521344-3-21-23455643313--4-1--4-34-----3-1---1  100
44 Sola cord -------------------------1------1---3----------------------------------------------------------------  100
34 Nica phys --------3-----75376777777767777777577777767777775766777673276456557577-6777-746443255774------------  1010
36 Datu mete ------------------------------------------------1-----------------------6------------------------  1010
37 Calo proc ---------------------------------------1-------------------------------2------------------------  1010
 2 Buxu hild 6567556667756656--4-3354167555665557665666465655667657774666666-7766663663-245-674367--3-5-6634776535  10110
14 Term ina2 ---------------------------------------------------------------------------------------------------------  10110
22 Eucl race --2-1------------------------------------------------------------------------------------------------  10110
45 Rici comm ---------------------1----------------------------1----------------------------------1-------------  10110
 3 Ficu vast -1------------1-------1-------11---------1---------11--1-1---------1---1-----111-1-------1---------  10111
20 Grew bico ---------------------------------------------------------------------------------------------------------  1100
27 Tare grav ---------------------------------------------------------------------------------------------------------  11010
 4 Ficu syca ---------------------------------------------------------------------------------------------------1--  110110
23 Comb moll ---------------------------------------------------------------------------------------------------------  110110
29 Zizy spin ---------------------------------------------------------------------------------------------------------  110110
31 Trem orie ---------------------------------------------------------------------------------------------------------  110110
32 Drac ombe ----------------------------------------------------------------------------------------------------1-  110110
41 Indi coer ---------------------------------------------------------------------------------------------42544--  110110
42 Salv pers ---------------------------------------------------------------------------------------------------------  110110
10 Acac seya ------------------------------------------------------2-----------1-------1--------5-5721777766--  110111
11 Acac asak ---------------------------------------------------------------------------------------------------------  110111
43 Cari spin ---------------------------------------------------------------------------------------------------1--  110111
 5 Ficu cord ---------------------------------------------------------------------------------------------------------  111
 8 Rhus nata ---------------------------------------------------------------------------------------------------------  111
17 Comm kua  ---1----------------------------------------------------------------------------------------------11-3  111
28 Dodo visc ---------------------------------------------------------------------------------------------------------  111

           1111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111
           0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000011111111111
           0000000000000011111111111111111111111111111111111111111111111111111111111111111111111111000000000000
           0011111111111000000000000000000000000000000000000000000000000000000001111111111111000000000011
           1100011111111100000000000000000000000000000000000000000000000000001111111000000000111100000111111100
           11   0000000110000000000001111111111111111111111111111111111111111111111000000010000111111        00001101

           EEEEEEEEEEEEEFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFGGGGGGGGGGGGGGHHHHHHHHHHH
```

```
             11222222333333122223333312222
             06224445111222633451112264444
             21124693057145278524890241380

21 Grew vill -----------------------------  000
26 Pist falc --1-----------3----1---1-1--  000
 1 Juni proc -----------------------------  0010
13 Side masc -----------------------------  0010
16 Olea euro -1-----------1-2-2--2---1-1-1  0010
40 Baby whit -----------------------------  0010
35 Eury arab ----------------1------------  0011
 6 Tarc camp -----------------12-----2----  0100
24 Meyt unda -----------------------------  0100
30 Bauh tome -----------------------------  0100
19 Grew eryt -----------------------------  01010
39 Psia punc 23------2-1---63243--4-------  01010
 7 Rhus reti -----------------------------  01011
15 Mang indi -----------------------------  01011
33 Apoc ynac -----------------------------  01011
 9 Acac etba ------1--12---11--1533-1---1-  011
12 Acac horr -----------------------------  011
18 Grew velu ----2-1---1---311--1---3--22-  011
38 With somn -----------------------------  100
44 Sola cord -----------------------------  100
34 Nica phys -----------------------------  1010
36 Datu mete -----------------------------  1010
37 Calo proc -----------------------------  1010
 2 Buxu hild 65655562776676554-54352464-31  10110
14 Term ina2 -----------------------------  10110
22 Eucl race -----------------------------  10110
45 Rici comm ----------------------------1  10110
 3 Ficu vast ----------------1---1-1------  10111
20 Grew bico ---------------------2-------  1100
27 Tare grav --------------------------4--2  11010
 4 Ficu syca -----------12---------------3  110110
23 Comb moll -2--12-2--1112------1--------  110110
29 Zizy spin -------1-----------21--------  110110
31 Trem orie ------------------1---------  110110
32 Drac ombe -----------------------------  110110
41 Indi coer -4--2-4--24324131-32-------2-  110110
42 Salv pers ---------4-------------------  110110
10 Acac seya -1--6-3-547655-226164455-----  110111
11 Acac asak -----------1---------5-2-----  110111
43 Cari spin -----------------------1-----  110111
 5 Ficu cord ----------------------------2  111
 8 Rhus nata -2--4---1--1-1322333----14221  111
17 Comm kua  5145--4-15233-3-1232--11-----  111
28 Dodo visc -----------------42--552-----  111

             11111111111111111111111111111
             11111111111111111111111111111
             00000000000000000000000011111
             11111111111111111111111100001
             0000000000000011111111111
             1111111111111110000001111

             HHHHHHHHHHHHHHHHHHHHHHHHHHHHH
```

7.5 Appendix E: Juniper condition model

i) Maximal model

```
glm(formula = log(Mean.condition + 1) ~ Altitude * Slope * Grazing *
    Aspect, family = "gaussian")

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.83820  -0.15744  -0.03278   0.16272   0.92360

Coefficients: (3 not defined because of singularities)
                                  Estimate Std. Error t value Pr(>|t|)
(Intercept)                      1.968e-02  6.169e+00   0.003    0.997
Altitude                         3.882e-04  4.135e-03   0.094    0.925
Slope                           -1.261e-01  2.248e-01  -0.561    0.576
Grazing                         -6.868e-01  2.277e+00  -0.302    0.763
AspectN                         -1.285e+00  6.464e+00  -0.199    0.843
AspectNE                        -5.183e-01  8.088e+00  -0.064    0.949
AspectNW                        -4.878e+00  7.411e+00  -0.658    0.511
AspectP                         -3.602e-01  6.307e+00  -0.057    0.955
AspectS                          7.242e-01  6.931e+00   0.104    0.917
AspectSE                        -7.546e+00  8.225e+00  -0.917    0.360
AspectSW                        -7.031e+00  9.481e+00  -0.742    0.459
AspectW                         -1.833e+00  6.837e+00  -0.268    0.789
Altitude:Slope                   7.824e-05  1.506e-04   0.520    0.604
Altitude:Grazing                 3.597e-04  1.527e-03   0.236    0.814
Slope:Grazing                    8.870e-02  1.003e-01   0.885    0.377
Altitude:AspectN                 8.165e-04  4.326e-03   0.189    0.850
Altitude:AspectNE               -1.504e-04  5.423e-03  -0.028    0.978
Altitude:AspectNW                3.487e-03  5.016e-03   0.695    0.488
Altitude:AspectP                 2.472e-04  4.218e-03   0.059    0.953
Altitude:AspectS                -4.045e-04  4.600e-03  -0.088    0.930
Altitude:AspectSE                5.049e-03  5.356e-03   0.943    0.347
Altitude:AspectSW                4.206e-03  5.993e-03   0.702    0.484
Altitude:AspectW                 1.155e-03  4.625e-03   0.250    0.803
Slope:AspectN                    1.024e-01  2.330e-01   0.440    0.661
Slope:AspectNE                  -1.385e-01  3.747e-01  -0.370    0.712
Slope:AspectNW                   1.814e-01  2.717e-01   0.668    0.505
Slope:AspectP                    2.494e-02  3.185e-02   0.783    0.435
Slope:AspectS                    1.958e-02  2.596e-01   0.075    0.940
Slope:AspectSE                   2.595e-01  3.682e-01   0.705    0.482
Slope:AspectSW                   1.989e-01  5.256e-01   0.378    0.706
Slope:AspectW                    7.173e-03  2.605e-01   0.028    0.978
Grazing:AspectN                  5.924e-02  2.389e+00   0.025    0.980
Grazing:AspectNE                -2.020e+00  3.257e+00  -0.620    0.536
Grazing:AspectNW                 5.138e+00  4.746e+00   1.083    0.280
Grazing:AspectP                  6.035e-01  2.322e+00   0.260    0.795
Grazing:AspectS                 -1.803e+00  2.885e+00  -0.625    0.533
Grazing:AspectSE                 2.607e+00  3.126e+00   0.834    0.405
Grazing:AspectSW                 5.822e+00  1.033e+01   0.564    0.573
Grazing:AspectW                 -3.070e-01  2.656e+00  -0.116    0.908
Altitude:Slope:Grazing          -5.454e-05  6.691e-05  -0.815    0.416
Altitude:Slope:AspectN          -6.294e-05  1.561e-04  -0.403    0.687
Altitude:Slope:AspectNE          1.109e-04  2.473e-04   0.448    0.654
Altitude:Slope:AspectNW         -1.265e-04  1.834e-04  -0.690    0.491
Altitude:Slope:AspectP                  NA         NA      NA       NA
Altitude:Slope:AspectS          -1.560e-05  1.708e-04  -0.091    0.927
Altitude:Slope:AspectSE         -1.743e-04  2.333e-04  -0.747    0.456
Altitude:Slope:AspectSW         -9.746e-05  3.551e-04  -0.274    0.784
Altitude:Slope:AspectW          -2.907e-06  1.743e-04  -0.017    0.987
Altitude:Grazing:AspectN        -4.099e-05  1.598e-03  -0.026    0.980
Altitude:Grazing:AspectNE        1.528e-03  2.184e-03   0.700    0.485
Altitude:Grazing:AspectNW       -3.579e-03  3.226e-03  -1.109    0.269
Altitude:Grazing:AspectP        -3.880e-04  1.555e-03  -0.250    0.803
Altitude:Grazing:AspectS         1.206e-03  1.917e-03   0.629    0.530
Altitude:Grazing:AspectSE       -1.742e-03  2.076e-03  -0.839    0.402
Altitude:Grazing:AspectSW       -3.717e-03  6.352e-03  -0.585    0.559
Altitude:Grazing:AspectW         2.062e-04  1.772e-03   0.116    0.907
Slope:Grazing:AspectN           -7.091e-02  1.058e-01  -0.670    0.504
Slope:Grazing:AspectNE           9.250e-02  1.823e-01   0.507    0.613
Slope:Grazing:AspectNW          -2.006e-01  1.838e-01  -1.092    0.276
```

```
Slope:Grazing:AspectP                     NA          NA       NA        NA
Slope:Grazing:AspectS              3.486e-03   1.237e-01    0.028     0.978
Slope:Grazing:AspectSE            -5.886e-02   1.585e-01   -0.371     0.711
Slope:Grazing:AspectSW            -2.908e-01   5.227e-01   -0.556     0.579
Slope:Grazing:AspectW             -7.727e-03   1.238e-01   -0.062     0.950
Altitude:Slope:Grazing:AspectN     4.503e-05   7.053e-05    0.638     0.524
Altitude:Slope:Grazing:AspectNE   -7.045e-05   1.204e-04   -0.585     0.559
Altitude:Slope:Grazing:AspectNW    1.376e-04   1.254e-04    1.098     0.274
Altitude:Slope:Grazing:AspectP            NA          NA       NA        NA
Altitude:Slope:Grazing:AspectS    -4.223e-06   8.095e-05   -0.052     0.958
Altitude:Slope:Grazing:AspectSE    3.880e-05   1.023e-04    0.379     0.705
Altitude:Slope:Grazing:AspectSW    1.785e-04   3.083e-04    0.579     0.563
Altitude:Slope:Grazing:AspectW     6.650e-06   8.103e-05    0.082     0.935

(Dispersion parameter for gaussian family taken to be 0.09196064)

    Null deviance: 38.875  on 273  degrees of freedom
Residual deviance: 18.852  on 205  degrees of freedom
  (56 observations deleted due to missingness)
AIC: 184.21

Number of Fisher Scoring iterations: 2
```

ii) Table of model history

Key: Al = Altitude, S = Slope, G = Grazing, As = Aspect, AIC = Akaike Information Criterion, MAM = Minimum adequate model. Crosses (×) indicate that the parameter is present in the model.

Model	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**MAM**
Al	×	×	×	×	×	×	×	×	×	×	×	×
S	×	×	×	×	×	×	×	×	×			
G	×	×	×	×	×	×	×	×	×	×		
As	×	×	×	×	×	×	×	×	×	×	×	
Al:S	×	×	×	×	×	×	×	×				
Al:G	×	×	×	×	×	×	×	×	×	×	×	×
Al:As	×	×	×	×	×	×	×	×	×	×	×	
S:G	×	×	×	×	×	×	×	×	×	×	×	×
S:As	×	×	×	×								
G:As	×	×	×	×	×	×						
Al:S:G	×	×	×	×	×	×	×					
Al:S:As	×	×										
Al:G:As	×	×	×	×	×							
S:G:As	×	×	×									
Al:S:G:As	×											
AIC	184.21	175.21	163.25	155.49	150.45	147.53	139.41	139.39	137.58	135.75	135.46	**126.05**

7.6 Appendix F: Francolin presence model*

i) Maximal model

```
Generalized linear mixed model fit using PQL
Formula: Presence ~ Altitude * Grazing * Tree.cover * Mean.condition + Community +
       (1 | Transect)
 Family: binomial(logit link)
   AIC   BIC logLik deviance
 207.1 290.2 -79.57    159.1
Random effects:
 Groups   Name        Variance Std.Dev.
 Transect (Intercept) 5e-10    2.2361e-05
number of obs: 235, groups: Transect, 26

Estimated scale (compare to  1 )  0.8981712

Fixed effects:
                                            Estimate Std. Error   z value Pr(>|z|)
(Intercept)                               -3.069e+01  6.959e+01   -0.4410    0.659
Altitude                                   1.529e-02  4.941e-02    0.3095    0.757
Grazing                                    9.056e+00  2.515e+01    0.3601    0.719
Tree.cover                                 1.165e+00  1.838e+00    0.6338    0.526
Mean.condition                             2.814e+01  3.828e+01    0.7351    0.462
CommunityB                                -2.154e+02  2.023e+07 -1.06e-05    1.000
CommunityC                                -2.181e+02  1.431e+07 -1.52e-05    1.000
CommunityD                                 3.734e-01  1.515e+00    0.2465    0.805
CommunityE                                 1.194e+00  1.379e+00    0.8660    0.386
CommunityF                                 1.566e+00  1.639e+00    0.9554    0.339
CommunityG                                 2.757e+00  1.772e+00    1.5555    0.120
CommunityH                                 1.675e+00  1.724e+00    0.9712    0.331
Altitude:Grazing                          -4.417e-03  1.794e-02   -0.2462    0.806
Altitude:Tree.cover                       -5.801e-04  1.284e-03   -0.4518    0.651
Grazing:Tree.cover                        -4.398e-01  7.512e-01   -0.5854    0.558
Altitude:Mean.condition                   -1.785e-02  2.558e-02   -0.6978    0.485
Grazing:Mean.condition                    -1.522e+01  1.298e+01   -1.1722    0.241
Tree.cover:Mean.condition                 -8.752e-01  9.310e-01   -0.9401    0.347
Altitude:Grazing:Tree.cover                2.063e-04  5.305e-04    0.3889    0.697
Altitude:Grazing:Mean.condition            9.342e-03  8.644e-03    1.0807    0.280
Altitude:Tree.cover:Mean.condition         5.244e-04  6.146e-04    0.8533    0.393
Grazing:Tree.cover:Mean.condition          4.718e-01  3.404e-01    1.3861    0.166
Altitude:Grazing:Tree.cover:Mean.condition -2.776e-04 2.273e-04   -1.2211    0.222
```

* The variable of 'Community' was not added as an interaction with any of the other variables in the maximal model because the large number of factors in Community (8) overcomplicated the model, producing an error. Community is thus shown here only as a main effect, after discovering from separate modelling that it did not have any significant interactions with the other variables, in relation to bird presence.

```
Correlation of Fixed Effects:

            (Intr) Altitd Grazng Tr.cvr Mn.cnd CmmnA2 CmmnA3 CmmnA4 CmmnA5 CmmnA6 CmmnA7 CmmnA8 Altt:G Alt:T. Grz:T. Alt:M. Grz:M.
Altitude    -0.997
Grazing     -0.968  0.966
Tree.cover  -0.927  0.918  0.938
Mean.condtn -0.888  0.867  0.836  0.778
CommunityB   0.000  0.000  0.000  0.000  0.000
CommunityC   0.000  0.000  0.000  0.000  0.000  0.000
CommunityD  -0.107  0.087  0.079  0.039  0.150  0.000  0.000
CommunityE  -0.134  0.112  0.120  0.077  0.121  0.000  0.000  0.764
CommunityF  -0.223  0.205  0.224  0.164  0.174  0.000  0.000  0.647  0.815
CommunityG  -0.195  0.177  0.185  0.131  0.179  0.000  0.000  0.613  0.769  0.860
CommunityH  -0.258  0.229  0.226  0.227  0.254  0.000  0.000  0.587  0.775  0.731  0.683
Alttd:Grzng  0.963 -0.965 -0.998 -0.930 -0.811  0.000  0.000 -0.070 -0.113 -0.224 -0.183 -0.213
Alttd:Tr.cv  0.931 -0.928 -0.942 -0.996 -0.767  0.000  0.000 -0.032 -0.079 -0.161 -0.129 -0.218  0.938
Grzng:Tr.cv  0.826 -0.818 -0.910 -0.949 -0.669  0.000  0.000 -0.018 -0.079 -0.161 -0.121 -0.221  0.905  0.947
Alttd:Mn.cn  0.911 -0.894 -0.859 -0.796 -0.996  0.000  0.000 -0.147 -0.115 -0.172 -0.174 -0.242  0.839  0.790  0.686
Grzng:Mn.cn  0.874 -0.851 -0.852 -0.789 -0.973  0.000  0.000 -0.156 -0.154 -0.218 -0.227 -0.262  0.825  0.778  0.720  0.969
Tr.cvr:Mn.c  0.874 -0.848 -0.856 -0.887 -0.934  0.000  0.000 -0.110 -0.079 -0.144 -0.136 -0.234  0.829  0.864  0.808  0.927  0.927
Alttd:Gr:T. -0.821  0.817  0.907  0.942  0.651  0.000  0.000  0.007  0.077  0.154  0.116  0.210 -0.906 -0.945 -0.997 -0.672 -0.700
Alttd:Gr:M. -0.902  0.884  0.888  0.817  0.970  0.000  0.000  0.146  0.144  0.219  0.221  0.252 -0.866 -0.811 -0.753 -0.974 -0.995
Alttd:T.:M. -0.901  0.880  0.884  0.910  0.936  0.000  0.000  0.101  0.079  0.142  0.133  0.228 -0.862 -0.894 -0.834 -0.936 -0.930
Grzng:T.:M. -0.824  0.798  0.856  0.875  0.862  0.000  0.000  0.128  0.109  0.185  0.173  0.257 -0.828 -0.853 -0.868 -0.856 -0.917
Alt:G:T.:M.  0.842 -0.821 -0.883 -0.898 -0.853  0.000  0.000 -0.113 -0.103 -0.177 -0.163 -0.248  0.861  0.883  0.902  0.855  0.908


            Tr.:M. Al:G:T. A:G:M. A:T.:M G:T.:M
Altitude
Grazing
Tree.cover
Mean.condtn
CommunityB
CommunityC
CommunityD
CommunityE
CommunityF
CommunityG
CommunityH
Alttd:Grzng
Alttd:Tr.cv
Grzng:Tr.cv
Alttd:Mn.cn
Grzng:Mn.cn
Tr.cvr:Mn.c
Alttd:Gr:T. -0.783
Alttd:Gr:M. -0.926  0.738
Alttd:T.:M. -0.996  0.814   0.936
Grzng:T.:M. -0.955  0.841   0.917  0.954
Alt:G:T.:M.  0.946 -0.882  -0.918 -0.953 -0.994
```

ii) Table of model history

Key: A = Altitude, G = Grazing, T = Tree cover, M = Mean juniper condition, C = Comunity, AIC = Akaike Information Criterion, MAM = Minimum adequate model. Crosses (×) indicate that the parameter is present in the model.

Model	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**MAM**
A	×	×	×	×	×	×	×	×	×	
G	×	×	×	×	×	×	×	×		
T	×	×	×	×	×	×	×	×	×	×
M	×	×	×	×	×	×	×	×	×	×
C	×	×	×	×	×	×	×			
A:G	×	×	×	×						
A:T	×	×	×	×	×					
A:M	×	×	×							
G:T	×	×	×	×	×	×	×	×	×	×
G:M	×	×	×	×	×	×	×	×	×	×
T:M	×	×	×	×	×	×				
A:G:T	×	×								
A:G:M	×	×								
A:T:M	×	×								
G:T:M	×	×								
A:G:T:M	×									
AIC	207.1	206.7	204.4	202.5	200.9	200.4	199.0	195.4	193.4	**191.7**

7.7 Appendix G: Conservation Action Plan

The Forêt du Day urgently needs to be nationally and internationally recognised as a nature reserve of international importance. Strong governmental support and adequate funding from the Ministry of Environment is required. Locally, support needs to be gained from the chief of the province of Day and at least one influential person in each village, such as schoolteachers, imams and village chiefs. Communication of the international importance of the ecosystem to the local residents will give them an opportunity to take pride in and conserve their forest.

1 The grazing-exclusion zone

Francolin presence is associated with tree cover and juniper health is associated with altitude. We can address these issues in a system of protected zones in the Forêt du Day. Because francolins are also associated with declining juniper health and increasing cover of box trees, simply protecting junipers only will not aid francolin conservation. A zone is therefore proposed chiefly for the protection of francolins (below). However, it is hoped that if adequate juniper habitat can be provided for francolins, they will re-colonise these areas.

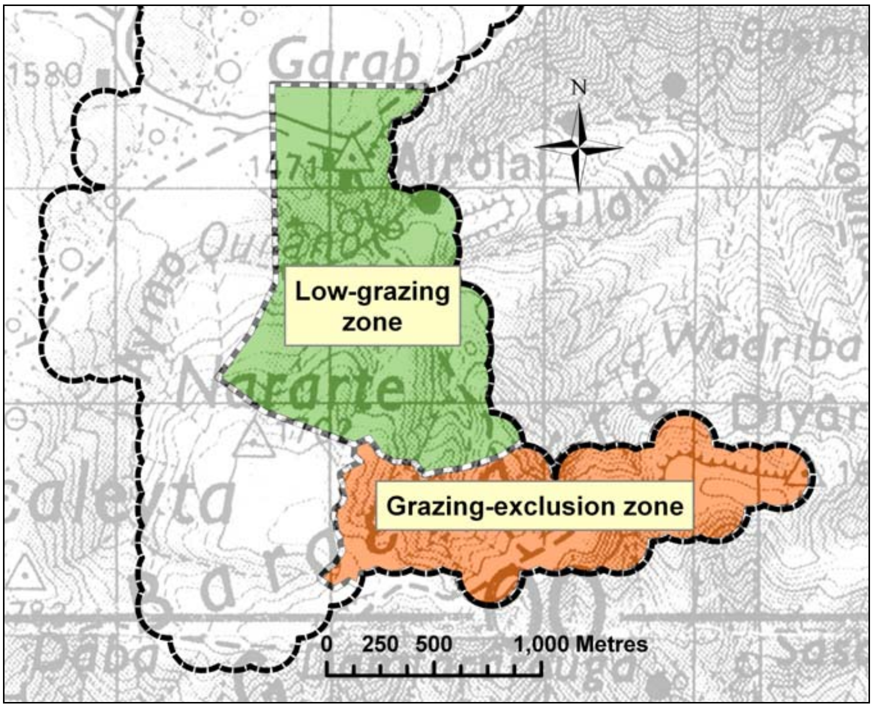

Figure 1 Proposed grazing-exclusion and low-grazing zones. The dashed black-and-white lines show where walls/fences could be built.

To protect the remaining juniper forest, a grazing-exclusion zone is proposed for the area where juniper health is highest (above 50% on average). This corresponds to a continuous area of 114 ha (1.14 km^2) on the eastern half of Barabarre mountain (Figure 1). This zone consists of a diverse range of habitats: plateau juniper and box forest, slopes of varying steepness, rocky cliffs and the highest peak in the forest. This area is not heavily grazed at present and contained 26% of the francolin observations in the study.

It is hoped that the diverse range of habitats would be conducive to francolin colonisation, and the fact that the area in the proposed grazing-exclusion zone is not heavily grazed at present means that land-take of pastures will be minimized. It is crucial to protect this section of forest, as it currently has the highest juniper health. Tree cover of other trees such as box is also high, providing favourable francolin habitat. In the future, if grazing levels were to increase (for example if other areas became exhausted of pasture), this remnant forest would be highly threatened.

The zone can be protected using a traditional low-level stone wall with broken dead branches, which requires minimal costs and man-power to build and has been used in the existing exclosures. Only one continuous section of wall needs to be constructed from the northern to southern ridges of Barabarre that would be approximately 1.75 km long. It is important, however, to still allow full access rights to all villagers in the region, who may collect dead wood in the zone for cooking and use the area for leisure. The threat of felling of living trees is negligible, as it is currently prohibited with strong penalties in a cultural law system.

2 The low-grazing zone

The eastern region of the Garab plateau and the eastern slopes of Nararte should be designated as a low-grazing zone (Figure 1). This zone has suitable francolin habitat – high total tree cover, but low juniper cover. The protection area would be less strict than the grazing-exclusion zone, but should only be grazed for example, one day a week by each of the 5 villages with weekends being non-grazing days. This would reduce the number of cows grazing at any one time in the zone by up to 85% on average, depending on the system of rotation between villages and number of cows allowed in the zone on a given day. The zone contains 35% of the francolin observations from the study and total tree cover of 40% or more. Plateau, slope and wadi habitats are all represented. Given the current high levels of grazing in the zone, it would be difficult to convince villagers to completely exclude their cattle from the region. Load-shedding of grazing is an optimal solution because it reduces grazing pressure significantly (e.g. four fifths of all cows can be excluded at any one time), allowing better tree regeneration, which will be beneficial to francolins (as has been concluded from the model). The higher quality of pasture that will be available as a result of reducing grazing intensity will also be favourable for the cows that graze there, and the villagers would therefore benefit from this solution. However, this alone may not be enough compensation for lost opportunities and other direct payments could be considered, perhaps in the form of food supplements for animals. The zone would be 116 ha (1.16 km^2) and the wall needed would be approximately 3 km long.

If the current trend of increased frequency of drought continues, sharing of grazing pastures in such a way will hopefully prolong the availability of pastures through dry periods, and reduce the time needed to herd cows to the frontier with Ethiopia – a long and strenuous journey that villagers state costs the lives of many animals.

3 Enforcement of reduced-grazing areas

The Barabarre grazing-exclusion zone would not need a daily ranger due to its ease of implementation (the cattle will simply be excluded by the wall). Instead, a designated person would need to check for compliance by villagers by inspection of the wall for break-ins, once or twice a week. Maintenance of the wall could be carried out by the same person – who would need to check for gaps in the wall caused by cattle. Currently, grazing is excluded by such walls between the Garab plateau and Adonta for most of the year. The penalties for admitting cattle in the non-grazing season are already very high (a certain number of the law-evader's animals are killed) – the same penalties could be extended for the Barabarre zone, therefore reducing the complexity of the system's implementation.

A similar low-level wall would need to surround the western edge of the low-grazing zone (the eastern cliffs act as a natural wall for the eastern edge of the zone). The wall would have two or three entrances, to be guarded by the herdsmen taking their cattle to the low-exclusion zone on their permitted day. Guarding of the entrances would be in the herdsman's best interests, as his cows would be benefiting from the zone's pastures on that particular day. The current penalty system could also be extended to this low-grazing zone.

4 Propagation of the juniper forest and investment in education

With unemployment at high levels in the province of Day (>80%, A. Dabaleh, chief of province of Day, pers. comm.), there is an opportunity to employ a few individuals to start a juniper nursery in a specified area, either in a village (close to piped water supplies) or in the forest near one of the now rarely-used wells (people have had piped water since 2003).

This is not proposed as a priority mechanism for the conservation of the forest ecosystem, but as an incentive for villagers to diversify their income sources by involving them in conservation of their forest. Salaries would need to be paid by the government, and their support would thus be required to fund this project.

A juniper nursery would allow augmentation of the young juniper stands in the forest, currently lacking. Once young trees are of a size that can withstand grazing pressure (probably 3 – 5 years old), they can be replanted in areas of forest that have low regeneration and a conducive climate to juniper growth (e.g. high altitude areas). Planting would need to be in the wet season to maximize survival rates.

This project has an educative component and school children could become involved in the juniper nursery. Education books about the birds of Djibouti have already been produced, and the school in Day village is currently piloting the scheme. Such schemes should continue and a francolin education programme can include field trips of small numbers of children to the forest's francolin zones. Binoculars and other such equipment would be useful and fun tools available for use by schoolchildren, to aid education about nature in the forest.

5 Future areas for research

Unemployment can be tackled by employing certain villagers as researchers. Salaries would need to be reliable, paid for the duration of a project. Such projects should include a detailed radio-tracking survey of francolins for a duration of at least one year – in order to understand seasonal movements of the francolins. This would require training by qualified professionals from either Djiboutian or foreign NGOs. Other employment opportunities will be for a few francolin surveyors, who would carry out both daily point counts at fixed points and walk specific transects. This would complement the radio-tracking study by proving information about the seasonal spatial movements of francolins, but more importantly would obtain detailed time-series data to monitor the francolin population. Some point counts/transects must be within the grazing-exclusion and low-grazing zones, to record whether francolin numbers augment in the protected areas.

Ongoing six-monthly basic floral surveys need to be conducted by botanists in fixed quadrats around the forest, to assess the health of the juniper forest. Detailed data needs to be collected on health parameters of junipers (height and health index), the density of living and dead junipers in different areas and regeneration in the protected zones. Surveys should also include information on other trees present and their regeneration, and counts of indicator species of herbs and grass cover estimates.

Monitoring and evaluation systems must be in place to reassess the conservation actions quarterly. The national NGO Djibouti Nature will be the first point of call for field workers and any villagers who want to raise concerns (e.g. about the health of their herds) – these can be communicated through a key contact in the region, such as the school headmaster. The foreign and national NGOs will analyse the data collected quarterly and obtain any comments by villagers to assess the success of the conservation action plan and change it if necessary.

In addition, the francolin population in the Mabla Mountains should be surveyed as little is known about the size and status of this population.