Habitat use of the endangered and endemic Cretan Capricorn and impact of domestic goats

Christoforos Katsaounis
March, 2012

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by

Christoforos Katsaounis

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation for Environmental Modelling and Management.

Thesis Assessment Board

Chairman: Dr. Ir. C.A.M.J. Kees de Bie (University of Twente, ITC)
External examiner: Prof. Dr. Petter Pilesjö (Lund University)
First supervisor: Dr. A.G. Bert Toxopeus (University of Twente, ITC)
Second supervisor: Dr. Ir. T.A. Thomas Groen (University of Twente, ITC)

UNIVERSITY OF TWENTE.
ITC FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

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Abstract

The Cretan Capricorn (*Capra aegagrus cretica*) is an endangered subspecies of Wild Goat (*Capra aegagrus*) endemic to Crete, Greece. Part of its habitat is the Core Zone of the Samaria National Park (SNP CZ), a UNESCO Biosphere Reserve. No previous research has been conducted to its natural habitat; however in the present study GPS-collars were deployed for the first time. Aim of this study was to examine the Capricorn at 2 scales; (1) habitat use of the tracked Capricorns by relating vegetation groups and home ranges (HR) for three study period; (2) distribution modelling at the extent of their population in order to confirm general ecological knowledge on the animal that has not been previously tested and further examine the potential hybridization with free-ranging domestic goats. The home ranges of the collared Capricorns were calculated from the GPS telemetry data using fixed Kernel Density Estimators (KDE) for pre-mating, mating, and post-mating study periods. Five broad structural vegetation groups were derived from 65 vegetation samples in the study area by using TWINSPAN. An association between grouped hyper-temporal MODIS NDVI classes and the structural vegetation groups was established and was further used at both scales. Distribution modelling of the two target species was performed in Maxent, using 11 variables. Most important parameters for Capricorn occurrence were a large distance from roads and settlements, areas in proximity to steep slopes to use as escape terrain, altitude zone from 400 to 1500 m, and areas with coniferous forest. Results from the two different scales come to agreement about preference in habitat with areas with high tree cover. Overlapping areas between suitable habitats of the two target species were calculated for autumn, which includes the Capricorn's mating season. Possible contact zones in the SNP CZ covered 7.4% of its size, while other areas in its periphery were indicated. More research, in order to test this hypothesis and more robust occurrences off free-ranging domestic goats are required in order to determine whether this overlap is of significant importance. Furthermore, by mid-July 2012 the GPS database will represent a whole year. Annual HR's can then be compared to seasonal ones, which might further reveal possible seasonal preferences and knowledge on the ecology and behavior of the Cretan Capricorn.

Acknowledgements

First of all I would like to express my sincere gratitude to ITC for providing the funds for the GPS collar units and their accompanying equipment. Without this special equipment this study would not have been possible.

My deepest gratitude and special thanks goes to my two supervisors, Dr. Bert Toxopeus and Dr. Thomas Groen, for providing me their guidance through the thesis process, for sharing their expert knowledge, and for giving the right answers and forming the right questions. Also my deepest gratitude goes to Dr. Henk Kloosterman for his substantial contribution on the vegetation ecology part of this research.

This research would also not have been possible if it wasn't for the effort and coordination in the field from Dr. Petros Lymberakis (SNP MB, NHMC), especially for deploying the three GPS collars, being responsible for the data download, and for further sharing his expert knowledge during the whole process of this thesis research. Also my special thanks go to Maria Aksypolitou (SNP MB) for her help during data collection. I am most grateful to Mrs Christina Fournaraki (MAICh), for her time identifying all the plant species and to Mr. Manolis Abramakis (NHMC) for determining the plants palatability.

Also special thanks goes to some special friends in Crete for all their help during fieldwork: Katerina Giamalaki, Stayros Mylonas, Eleni Katsimente, Rita Vlaxou and last but not least, Dimitiris and Rena Batsakis.

My sincere thanks go to all the staff members, professors, lecturers, and lab assistants at the University of Lund and at ITC for making this course a great learning experience.

To every one of my GEM course fellows; you guys have been real gems throughout these months and I will never forget our times together through this experience! My deepest gratitude and appreciation goes to Marie Larnicol and the Svensson family for all their help during my time in Sweden.

My deepest gratitude and heartfelt appreciation goes to some very special people, the Avramides, Baxevanakis, Schmitz and Hess family and especially to my dear mother, for their encouragement and support during all these 18 months.

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Abbreviations

ASTER = Advanced Spaceborne Thermal Emission and Reflection Radiometer

AUC = Area Under Curve

BCV = Biased Cross Validation

CZ = Core Zone (of Samaria National Park)

DOP= Dilution of Precision

GPS = Global Positioning System

HR = Home Range

KDE = Kernel Density Estimators

LSCV = Least Squares Cross Validation

MAICh = Mediterranean Agronomic Institute of Chania

MODIS = Moderate Resolution Imaging Spectroradiometer

NDVI = Normalized Difference Vegetation Index

NHMC = Natural History Museum of Crete

PDOP= Positional Dilution of Precision

RA Agios Nikolaos = Rest Area Agios Nikolaos (1st capture location)

RA Samaria = Rest Area Samaria (2nd capture location)

RoC = Receiver operating Characteristic

SNP = Samaria National Park

VHF = Very High Frequency

VIF = Variance Inflation Factors

1.Introduction

1.1. Conservation status of the Cretan Capricorn

The Cretan Capricorn (*Capra aegagrus cretica* Schinz, 1838) is an endangered subspecies of Wild Goat (*Capra aegagrus*) endemic to Crete, Greece (Sfougaris et al., 1996). Also called by the locals as "Agrimi" (the wild one), it is the symbol of the White Mountains of west Crete, and of Crete in general. Until the beginning of the 20th century its range covered all three main mountain chains of Crete, however by 1960, the Capricorn was under critical threat with numbers below two hundred individuals and its population limited to the White Mountains (Legakis et al., 2009). The Samaria National Park (SNP) was founded in 1962 with its main purpose being the conservation of the Capricorn. It gradually became one of the main touristic attractions of the island with an average of 175,000 visitors per year (period: 1981-2010). Its core conservation area (SNP CZ) covers 4,850 hectares, while it has also been declared a UNESCO Biosphere Reserve in 1981 (UNESCO, 2005). As another conservation measure, populations of the Capricorn were also introduced to five uninhabited islets around Crete, south and central Greece (Legakis, et al., 2009).

No specific subspecies of Wild Goat (*Capra aegagrus*) is included in the IUCN red list of threatened species, although the species is listed as vulnerable due to its decreasing population trend (Weinberg et al., 2008). However, the most recent version of the The Red Book of Threatened Species of Greece (Legakis, et al., 2009), which uses the IUCN classification scheme, enlists the Cretan Capricorn in the endangered mammal species of the country. The Capricorn is protected by the Bern Convention, Annex II and the EU Directive 92/43, Annexes II and IV (Limberakis et al., 2009). Whereas the populations introduced in the islets had an increasing trend (Husband et al., 1984; Nicholson et al., 1992; Sfougaris, et al., 1996) , a recent study by the SNP Management Body estimated that the population of the Capricorn remains low –and possibly declining- in its natural habitat with approximately 600-700 individuals (Limberakis, et al., 2009). The Capricorn faces two major threats; poaching, and hybridization with free ranging domestic goats (Limberakis, et al., 2009; Sfougaris, et al., 1996).

1.2. Hybridization phenomena and human induced pressures

According to Rhymer & Simberloff (1996), hybridization is defined as interbreeding of individuals from genetically distinct populations, regardless of their taxonomic status, whereas introgressive hybridization involves gene flow between populations whose individuals hybridize, thus producing fertile offspring. The harmful effects of hybridization, with or without introgression, have led to the extinction of many populations and species in many plant and animal taxa (Rhymer, et al., 1996). In addition, hybridization has been identified as especially problematic for rare species that come into contact with other species that are more abundant (Rhymer, et al., 1996); (Allendorf et al., 2001), as is the case of the Cretan Capricorn and the feral domestic goats.

More specifically, concerning the genus *Capra*, different taxa can freely interbreed in captivity (Manceau et al., 1999), while producing fertile offspring (Pidancier et al., 2006). In the case of the Cretan Capricorn, the population in Dia islet which was introduced without the complete elimination of the domestic goats, was reported to be "obviously hybridized", despite their difference in mating seasons (Husband, et al., 1984).

On the whole, the widespread occurrence of free-ranging domestic or feral ungulates (goats, pigs), is raising concern that introgressive hybridization with wild populations might disrupt local adaptations, leading to population decline and loss of biodiversity (Randi, 2008). Apart from organism translocations, two more interacting human activities contribute to increased rates of hybridization; habitat modification and habitat fragmentation, which suggests that this problem will become even more serious in the future (Rhymer, et al., 1996).

Such human intervention in the natural environment has a long history in Crete (Ispikoudis et al., 1993). Especially since 1980, grazing pressure has significantly increased, as some of the mountainous communities of Crete had an increase of total number of sheep and goats by more than 200% between 1980 and 1990 (J. Hill et al., 1998). Although rangelands increased at about 18% in mountainous areas, by 1991 they were stocked with at least 50% more livestock than they could support in 1981. Overgrazing led to decrease in forest cover; increase in rangeland cover; and gradual degradation of both (Ispikoudis, et al., 1993). As another additional impact of overstocking in a similar Mediterranean environment (central Spain), it was found that the extensive goat livestock displaced the Iberian Ibex (*Capra pyrenaica*) to suboptimal habitats through interspecific resource competition (Acevedo et al., 2008).

1.3. Research problem and justification

Knowledge on a species actual occurrence, along with the spatial prediction of its distribution are important tools for the proposal of conservation measures and management planning (Sillero et al., 2009; Whittaker et al., 2005). In addition, identifying areas inhabited and impacted by ungulates in mountainous areas is recognised as a key requirement for evaluating their long-term effects on habitats and interaction with other species (Gross et al., 2002). More specifically for the Cretan Capricorn, recent estimations based on a helicopter survey showcase a low and possibly declining population due to the threats it is still facing (Limberakis, et al., 2009). It could be expected that further decline in the Capricorn population could eventually hurt the prestigious status of the SNP, while fragmented populations would be more susceptible to hybridization. Previous published studies on the Capricorn were not conducted in its natural habitat but in areas where it was introduced (Husband, et al., 1984; Nicholson, et al., 1992; Sfougaris, et al., 1996). This means that the seasonal movements and the habitat it occupies remain unknown to a large extent. Traditional ground surveys are very difficult to apply in the area due to the geomorphology and roughness of the mountainous terrain and also the elusive nature of the animal (Limberakis, et al., 2009). Furthermore, detailed monitoring becomes more difficult by the need to record animal movement in tandem with landscape condition, which in itself influences the animal's behaviour (Hulbert et al., 2001). Moreover, environmental parameters and conditions generally attributed to the animals preferences (steep slopes, altitude zone below the tree line, high tree cover, and distance from anthropogenic disturbance), have never been applied as input variables to a species distribution model.

1.4. GPS telemetry and combination with other methods

A solution to this issue can be given with the application of Global Positioning System (GPS) telemetry. Since mid-July of 2011 one male and two female Capricorns in the SNP CZ (all above three years old, in sexual maturity) have been equipped with GPS collars (Model GPS-Plus; Appendix A) (VECTRONICS Aerospace Berlin, 2010) for the first time. By deploying animal collars equipped with GPS, highly precise spatial and temporal location data about their movements are provided at predefined small time intervals (Hebblewhite et al., 2010). Compared with the older technology of Very High Frequency (VHF) radio-tracking systems the data acquisition comes with less work by operators, thus allowing reduced sampling intervals, and increased accuracy and performance (Rodgers, 2001). Availability of such high-quality, unbiased data on habitat use has improved the ecologists ability to identify important habitat for wildlife species and has made real contributions to conservation, especially in understanding human impacts on animals (Hebblewhite, et al., 2010). In addition, application of GPS collars has shown its usefulness in several studies of ungulates in their habitat (Jerina, 2009; Johnson et al., 2008; Poole et al., 2009).

The GPS telemetry data could be used as input for two methods at different scale; (1) seasonal home range analysis of the collared individuals in the SNP core zone, (2) predictive habitat modelling for all the White Mountains range.

The most frequently cited definition of an animal's home range is that of Burt (1943): " Home range is that area traversed by an individual in its normal activities of food gathering, mating and caring for young. Occasional sallies outside the area, perhaps exploratory in nature, should not be considered as in part of the home range". The most frequently applied method of calculating home range (HR) is kernel density estimators (KDE) (Fieberg, 2007; Kie et al., 2010). Large GPS telemetry datasets make it possible to apply these methods over relatively short periods of time such as weeks or months (Kie, et al., 2010). Home range analysis is also useful for describing habitat use, by overlaying a home range on a habitat map of the study area (Mabry et al., 2010).

On the other hand, predictive habitat distribution models have advanced as statistical methods, GIS and remote sensing technologies have grown in sophistication (Guisan et al., 2000). These modelling approaches rely on extrapolating spatially known associations between species occurrences and habitat features, which often are in the form of remotely sensed data (Osborne et al., 2007).

Further integration of remotely sensing data with tracking data allows animal preferences to be directly linked to the landscape from airborne or satellite images. Once the relationship between animal behaviour and the spectral and spatial analysis of the remotely-sensed images is modelled, these relationships can be extended to new images to predict and map likely animal behaviour (Handcock et al., 2009). A commonly applied approach on linking those relations is the normalized difference vegetation index (NDVI) (Leyequien et al., 2007). The NDVI has been used as a tool to relate climate, vegetation biomass and animal distribution in a defined time and space (Pettorelli et al., 2005). The biomass-based approach of applying NDVI has been used as an input for animal distributions models and has proven successful with herbivorous species that are sensitive to differences in vegetation phenology across an area (Leyequien, et al., 2007). Setting the Capricorns conservation issue aside, recent studies have addressed the need to better integrate GPS-telemetry data, remotely sensed data and availability of resources in animal monitoring studies (Handcock, et al., 2009; Hebblewhite, et al., 2010).

1.5. Target species

Both target species belong to the *Artiodactyla* order, the *Bovidae* family and the *Capra* genus.

1.5.1. Cretan Capricorn

The Cretan Capricorns usually live around 11-12 years, while sexual maturity for males comes at 3 years and for females at 2. They browse on stems, buds and leaves of shrubs and low trees, and grasses as well (Limberakis, et al., 2009). Horns in the males can reach up to 80 cm (Fig 1.1). Capricorns present a linear hierarchy based on age and sex, with older and consequently larger males being most dominant, which translates into more access to foraging and in males, increased access to mates (Nicholson, et al., 1992). Cretan Capricorns form groups of the same sex except during the mating season (Limberakis, et al., 2009). The mating season is signaled by anatomical and physiological changes at around two weeks after the first substantial rainfalls in late September/early October. In late October and early November rut behavior becomes more intense,

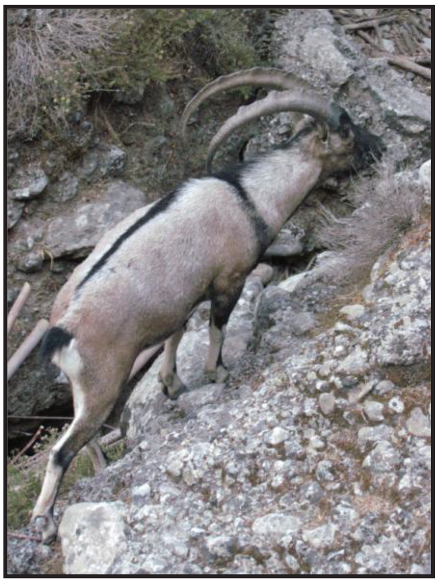

Figure 1.1: A 7 year old male Cretan Capricorn grazing near the main rest area in SNP CZ.

with single males often chasing single females even for several hours. Mating in late fall assures that kids will be dropped in early spring, when chances for survival are maximized (Husband, et al., 1984; Nicholson, et al., 1992).

1.5.2. Domestic Goat

Goats (*Capra aegagrus hircus*) were among the first species to be domesticated, around 10,000 years ago, in the Fertile Crescent of the Middle East. They are highly social and live in small to moderate group sizes which provides protection from predators, assistance in finding a mate and food, and help with care and protection of the young (Dwyer, 2009). Goat herding has been traditionally an important activity in Crete, which increased since Greece joined the EU in 1981. For example between 1981 - 1991 increase of goats numbers overall in Crete was 61.5%, while in mountainous areas it was 86.5% (Ispikoudis, et al., 1993). Concerning the mating season of the domestic goat in Crete it is in late summer, around August (Husband, et al., 1984).

Figure 1.2: A large herd of domestic goats, Omalos plateau, north of the SNP CZ main entrance.

1.6. Research objectives

There were two main objectives in the present research; (1) to examine the habitat use of the tracked Capricorns by relating vegetation groups and three study period home ranges; (2) to determine if and to which extent the ranges developed from the habitat suitability maps of the Capricorn and domestic goats overlap during autumn, which includes the Capricorns mating season (mid-October to mid-November).

1.6.1. Specific objectives

1. Analyze the GPS telemetry data from the collared Capricorn individuals in order to examine their home ranges during pre-mating, mating, and post-mating study periods.
2. Produce a vegetation classification of sampled sites and test for statistical significance between the resulting structural vegetation groups and available MODIS hyper-temporal NDVI classes or aggregated grouped classes.
3. Associate home ranges and vegetation classification through the MODIS hyper-temporal NDVI classes or aggregated grouped classes.
4. Generate a habitat suitability model for the Capricorn and the Domestic Goat for autumn (includes the Capricorns mating season).
5. Overlap resulting habitat suitability maps and examine size and locations of potential contact zones between the Capricorn and Domestic Goat.

1.7. Research questions

1. Are the home ranges of the three collared Capricorns significantly larger during the mating season compared to pre- and post-mating season?
2. Is there a statistically significant association between the structural vegetation groups and the MODIS hyper-temporal NDVI classes?
3. Do the structural vegetation groups that contribute most to the home ranges of the three collared Capricorns over the three study periods represent vegetation with high tree cover that provides shelter?
4. Do the predictor variables expected to be the most important for the distribution modelling of the Capricorn (altitude, slope, forest land cover, distance from anthropogenic disturbance) actually contribute most to its probability of occurrence?
5. Can the same set of predictor variables also be used for the distribution modelling of the free-ranging domestic goats?
6. Is there overlap between the ranges developed from the habitat suitability maps of the Capricorn and domestic goats during the autumn season?

1.8. Research Hypothesis

1) Ha: The home ranges of the three individual collared Capricorns are larger during the mating season compared to the pre-mating and post-mating study periods.
2) Ha: There is a statistically significant association between the classified structural vegetation groups and the MODIS hyper-temporal NDVI classes.
3) Ha: The structural vegetation groups that contribute most to the home ranges of the three collared Capricorns over the three study periods represent vegetation that provides shelter.
4) Ha: The predictor variables expected to be the most important for the distribution modelling of the Capricorn (altitude, slope, forest land cover, distance from anthropogenic disturbance) do actually contribute most to its probability of occurrence.
5) Ha: The same set of predictor variables can also be used for the distribution modelling of the free-ranging domestic goats.
6) Ha: There is overlap between the distributions of the Capricorn and Domestic Goat during autumn study period.

2. Materials and methods

2.1. Methodology overview

The major steps of the present research are summarised below:

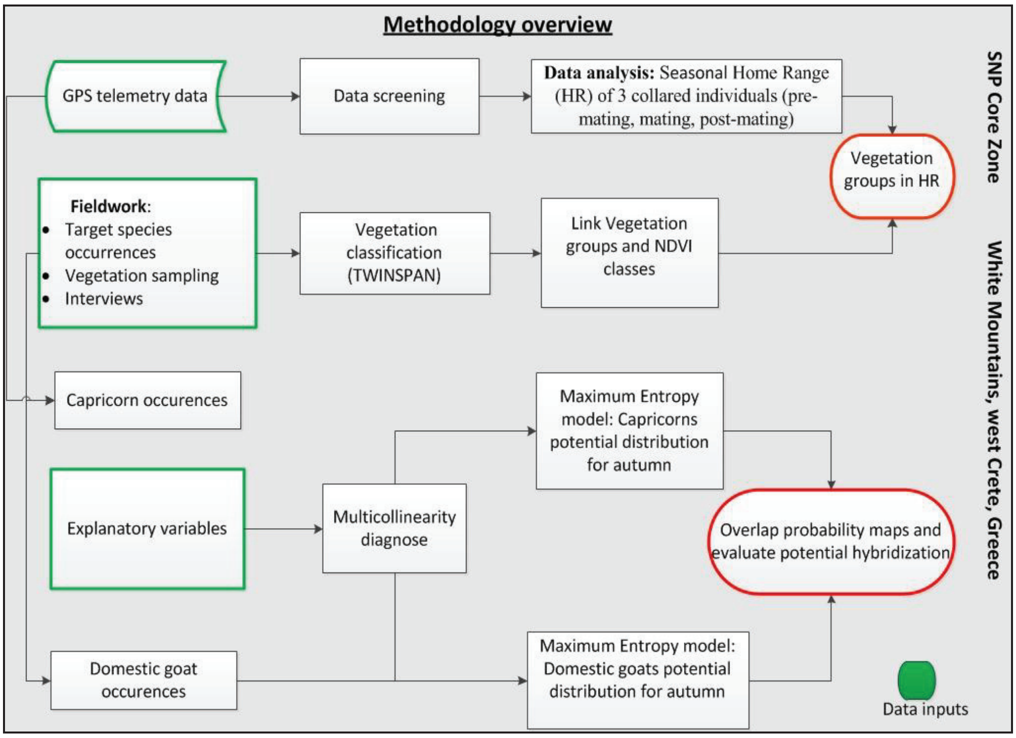

Figure 2.1: Methodology overview.

2.2. Study area: The White Mountains and SNP

There were two study areas for this research; (1) the broader area of the White Mountains, for the purposes of the vegetation sampling and classification as well as the habitat suitability modelling for the two target species; (2) the Core Zone of the White Mountains and Samaria National Park (SNP) as the study area of the three GPS-collared Capricorns, for the purpose of examining their seasonal home ranges. The White Mountains (Lefka Ori or Madares in Greek) are located in the Chania prefecture in west Crete. Crete is the largest island of Greece. The climate is Mediterranean with hot and dry summers and humid winters. Evergreen sclerophylous low shrub formations dominate, known as phrygana (Sluiter, 1998). Main agricultural land uses are olive trees groves and citrus orchards monocultures. The flora diversity is remarkable, as Crete holds 1828 species, 189 of which are endemic (Turland et al., 2008). More than half of the endemic flora (97 species) can be found in the White Mountains, 25 out of which are narrow endemic species only to that mountain range (2011). According to Strid (1996), 26.6% of the species found in the White Mountains above 1500 m are endemic to the island. The upper limit of the tree line on the southern side of the mountain range is at 1600–1650 m, while on the northern side the limit is up to 150 m higher (Vogiatzakis et al., 2003). Overall, the Cretan landscape is dominated by three large mountain ranges and several smaller ones. The White Mountains (Fig 2.2) are the largest of those, extending from east to west 45 km and from north to south 35 km.

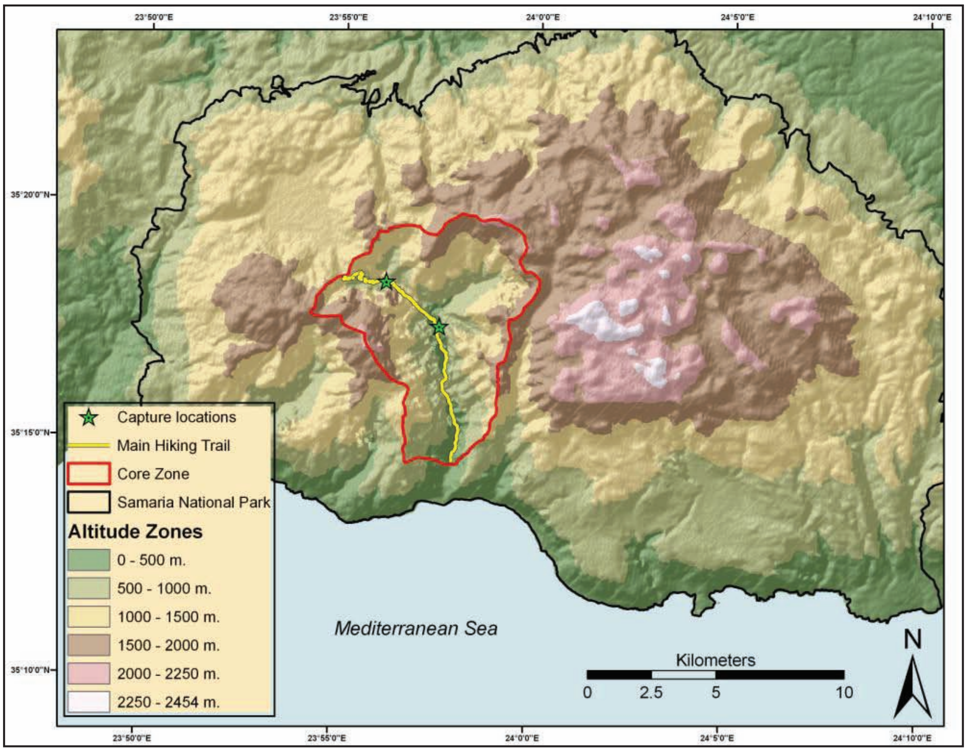

Figure 2.2: Study area; the White Mountains, Samaria National Park and Core Zone, Crete, Greece.

They include 57 summits over 2000 meters, the highest at 2454 m (Mt. Pahnes) and around 30 long gorges; the largest one being Samaria (18 km) (Spanakis, 1969). The White Mountains consist mainly of limestone, marble and dolomitic limestone; all calcareous rocks where karstic phenomenon of erosion is particularly strong. Erosion, combined with tectonic forces (due to the location of the island in relation to the two lithospheric plates of Africa and Eurasia) over a great period of time, have formed the numerous gorges of the study area (Papiomytoglou, 2006). In general, the gorges have a north-south orientation, where streams and rivers are often formed during winter and spring, ending in the Mediterranean Sea in the south coast of Crete. The mean annual precipitation in the weather station in the north entrance of Samaria gorge (at 1250 m) is 1672 mm (National Observatory of Athens, 2011), whereas for all Crete it is 453 mm (Sluiter, 1998).

The importance of the SNP with the large number of visitors it attracts was highlighted earlier. The area was also inhabited until 1962 (when it was declared a National Park) with a settlement located in the middle of the gorge. Nowadays it serves as the main rest area for the tourists and as residence for the park rangers in the restored buildings. It was also one of the two capture locations (Fig. 2.2).

2.3. Species occurrence data

Species occurrence data comprised of three sources; GPS telemetry, a past helicopter survey, and fieldwork observations.

2.3.1. Collar deployment

Three GPS collars (VECTRONICS Aerospace Berlin, 2010), model PLUS (Appendix A), were deployed in mid July 2011 from SNP personnel. The three collared animals are a young female (4 years old; capture location; Agios Nikolaos rest area, 650 m altitude, location called hereafter RA Agios Nikolaos), an old female (7 y.o., captured in Samaria abandoned settlement rest area, 350 m altitude, location hereafter called RA Samaria), and a young male (3 y.o., also captured in RA Samaria) (Fig. 2.2). The target for the fourth collar that was available was an old male, in order to represent four broad age/sex classes (young/old-male/female). During two visits at the SNP (16^{th}- 18^{th}, 26^{th}-27^{th} September) several unsuccessful attempts were made to capture an old male. The daily 16 GPS-fixes acquisition schedule (Table 2.1) had the shortest hourly intervals in the morning

(08:00 – 11:00) and in the evening (20:00 – 23:00) based on the diurnal behaviour of the Capricorn and because at these parts of the day they were most active (Nicholson, et al., 1992).

Table 2.1: Daily GPS fix acquisition schedule

03:00	15:00
05:00	17:00
06:30	18:30
08:00	20:00
09:00	21:00
10:00	22:00
11:00	23:00
13:30	01:30

2.3.2. GPS telemetry data acquisition and screening

The first dataset of GPS telemetry data was downloaded at the 16th of September in the SNP core zone, in proximity to the two locations were the three Capricorns were captured. The UHF handheld device (VECTRONICS Aerospace Berlin, 2010) was used. The data was later transferred from the UHF handheld device to a computer using the software GPS PLUS (VECTRONICS Aerospace Berlin, 2010). The last dataset that was available for the present research was downloaded from SNP personnel at 21/11/2011 for the first capture location (RA Agios Nikolaos) and at 02/12/2011 for the second (RA Samaria).

There are several sources of potential error and bias in radio-telemetry data, that should be taken into account (Frair et al., 2004). Firstly, the largest source of error for an animal monitoring study are missing data (Frair, et al., 2004), which occur when GPS radio-collars are set to acquire GPS locations on a predefined schedule but less than 100% of potential locations are in the database after data is retrieved from free-ranging animals. This is related with the activity of a collared animal by the position and orientation of the GPS antenna on the collars (D'Eon et al., 2005). Secondly, location inaccuracy in acquired data can lead to misclassification of habitat use depending on the magnitude of location error and the degree of landscape heterogeneity (Frair et al., 2010). GPS-telemetry data that have not undergone data screening have been demonstrated to be ±31 m at 95% of the time (D'Eon et al., 2002).

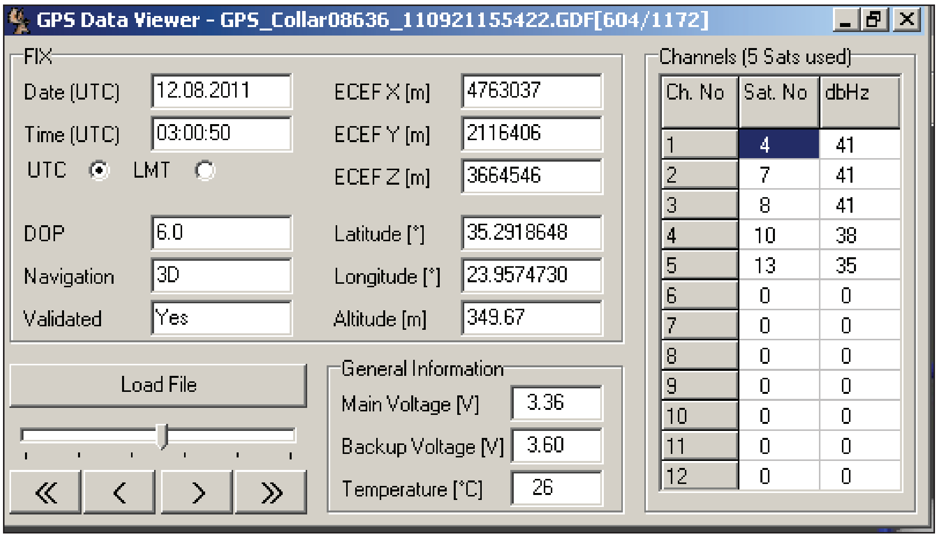

Figure 2.3: Example of GPS data visual inspection in Viewer mode of GPS PLUS software (Vectronics Aerospace).

The data screening process was carried out in Microsoft Excel. Following the guidelines given in the GPS Plus Collar Manager User's Manual (Zimmermann, 2011), the three descriptive classes (Fig. 2.3) that the GPS data came with were used for this process; "Navigation" (two or three-dimensional fixes), "Validated" (if positive, more than five satellites were used to record the fix, providing the highest accuracy possible), and "DOP" (Dilution of Precision). First criterion in the data screening was to keep only the three-dimensional fixes. This means that at least four satellites were used for the location acquisition, thus this is an accurate fix. In addition, after the three dimensional fixes are kept, the DOP value in the GPS data is in fact equal to the PDOP (Positional Dilution of Precision) (Zimmermann, 2011). PDOP is a three dimensional measure of the quality of GPS data, depending on satellite geometry. Lower values indicate higher location accuracy. It can be used as a means to further screen GPS telemetry data and reduce location error by deleting locations thought to be highly inaccurate (D'Eon, et al., 2005). A PDOP value of 10 was used as a threshold for deleting fixes above that value, which is often used in similar studies to considerably increase accuracy (D'Eon, et al., 2005; Poole, et al., 2009).

2.3.3. Helicopter survey

Another dataset of 19 Capricorn occurrences was available from a helicopter survey (from 13/9/2009) conducted from the SNP MB for a study focusing on estimating the Capricorns population (Limberakis, et al., 2009). The flight was conducted mainly over the SNP CZ and its periphery, further focusing to the steep, isolated gorges to the west of the CZ, as these parts are believed to hold the animal's population (Fig. 2.4). The capture-recapture method was used, thus locations recorded were confirmed from 2 independent observers. In most cases, Capricorns were observed in groups, usually comprised of 2 – 3 females, often with a kid in the groups. The total length of the helicopter flight in the study area was 230 km, while the observations were recorded only for a strip of 100 m from the helicopter, thus 23 km^2 were covered. Observations from free-ranging livestock were also recorded (69 in total); however they were not separated between sheep and domestic goats. Slope steepness was used as a criterion to separate between those observations. Whereas in other continents the absence of competition from goats has influenced the distribution of sheep, (e.g. in North America, the Rocky Mountain bighorn sheep ranges up to the highest summits) (Dwyer, 2009), in Asia and Europe sheep and goats have competed for habitat, resulting in sheep occupying lower mountain slopes and hills, while goats are found in steep cliff areas (Clutton-Brock, 1999). Any observation with a slope < 40˚ could be either goat or sheep, but slopes > 40˚ were selected as steep enough exclusively to goats (Fig. 2.4).

2.3.4. Fieldwork observations

Occurrences of the two target species were recorded during fieldwork. Three mountaineering maps (Anavasi, 2006) at 1:25,000 scale, covering all the White Mountains range, were handed out during interviews. Five additional Capricorn locations from recent observations, to account for autumn, were pointed out and digitized to the geo-database. Seventy five locations of domestic goats were recorded (Fig. 2.5). Often the locations for the domestic goat observations coincided or were very close to the vegetation sampling sites, due to the proximity both had to the road network. Two female domestic goats were observed in the SNP at the 27th of September (Fig 2.2).

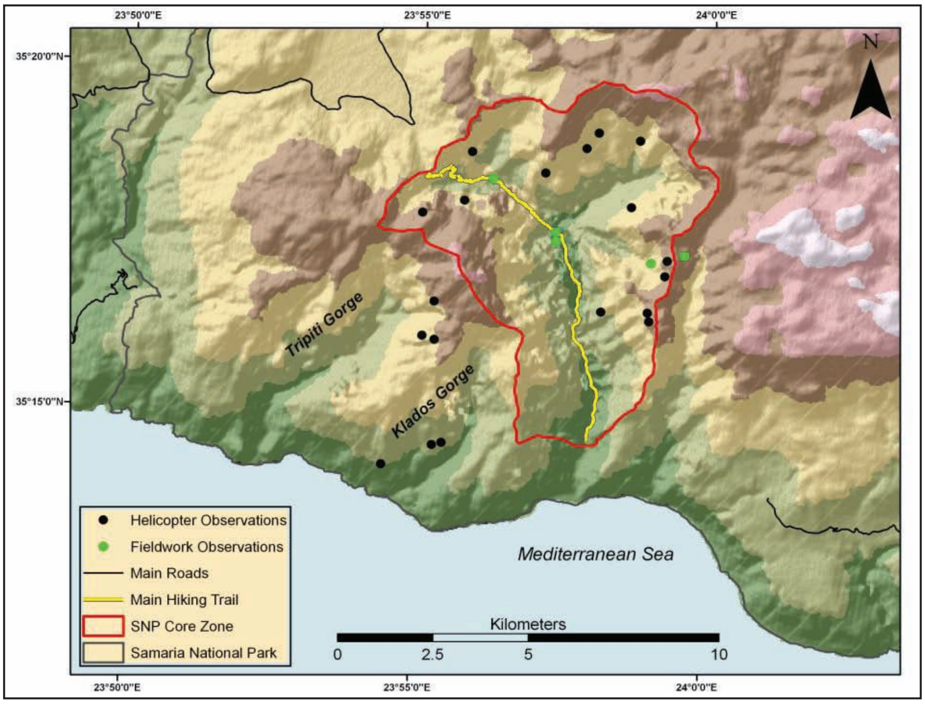

Figure 2.4: Capricorn observations from fieldwork and helicopter survey

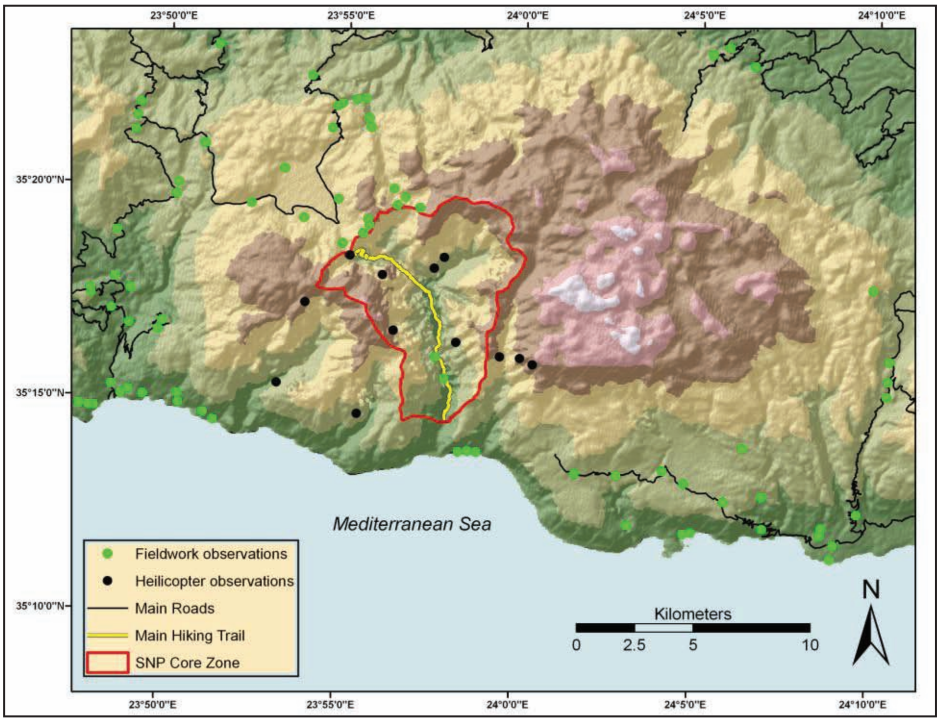

Figure 2.5: Domestic goat observations from fieldwork and helicopter survey

2.4. *Predictor variables*

A geo-database was created in GIS environment (ESRI, ArcMap 10.) where the explanatory variables were handled. All variables were projected to WGS 1984, UTM zone 35N geographic coordinate system. Variables were all clipped to the same extent of the study area and resampled to the same resolution (30 m) based on the ASTER Global Digital Elevation Model (DEM) used in the study. Finally, all predictors were converted to raster ASCII format in order to be imported in Maxent.

2.4.1. Topographic variables

All topographic variables were derived from the ASTER Global DEM that was directly downloaded from the U.S. Geological Survey website (USGS, 2011). The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is producing single-scene (60 x 60 kilometer) digital elevation models (DEM), having vertical (root-mean-squared-error) accuracies generally between 10 and 25 meters. Its resolution of 1 arc-second is approximately 28 meters at the latitude of Crete (approximately 35˚north of the equator). The DEM was resampled to 30 meters for convenience as raster resolution of all other variables was based on it (as explained in section 2.4.).

Slope and aspect of slope were derived from the DEM. The result of aspect was transformed from the initial 8 categorical compass directions to continuous degrees (0 – 360˚). This was done in order to reduce the possible effect of multicollinearity between the model variables, as it cannot be tested in the categorical ones. A further transformation from degrees to radians is necessary, as in the degrees both extremes of the gradient, 0 and 360, represent the same direction, north. Instead, aspect was converted to two linear continuous variables, eastness and northness, as follows (Zar, 1999):

$$\text{Eastness} = \sin((\text{aspect in degrees} * \pi)/180) \quad (2.1)$$

$$\text{Northness} = \cos((\text{aspect in degrees} * \pi)/180) \quad (2.2)$$

Northness quantifies the degree to which an aspect is north, and eastness, the degree to which it is east, e.g., northness for an angle of 360 degrees is 1, for 90 degrees is 0, and 180 degrees is –1. Following Poole et. al. (2009), the distance to escape route was delineated from slopes ≥40˚(84%), attempting to map terrain which will be steep enough to be used by the Capricorns to avoid predators, as flight to cover is the main anti-predator response of wild goats in general (Dwyer, 2009). Finally, a drainage system was produced (Hydrology tools, ArcMap 10) for the study area and a parameter of distance from rivers and streams was calculated from it (Poole, et al., 2009). All six topographic variables are listed in Appendix B.

2.4.2. Anthropogenic influence and Land Cover map

Two continuous variables were created to account for anthropogenic influence to the Capricorns occurrence; distance from road network (paved and unpaved roads), and distance from settlements. They were generated from the corresponding shapefiles provided by the University of Crete. A categorical land cover map was also created from the 3d level of the Corine land cover map (EEA, 2000), which was reclassified, merging together unsuitable areas for the Capricorn (e.g., agricultural or built-up areas), resulting in 9 classes from the initial 17. The three anthropogenic parameters are listed in Appendix B.

2.4.3. Biological variables

Animal movements can be related with satellite-based temporal estimates of resource availability (Hebblewhite, et al., 2010). Hyper temporal remotely sensed data are available from satellites such as MODIS (Moderate Resolution Infrared Satellite) which records vegetation indexes like NDVI (Huete et al., 2002). This provides ecologists with ready information on forage biomass, which can be matched temporally with GPS data (Running et al., 2004). In general, multi-temporal data offer possibilities to overcome the limitations of static habitat studies needed for conservation purposes (Leyequien, et al., 2007).

The dataset of MODIS hyper-temporal NDVI classes was prepared by (Taheri, 2010). Geometrically and radiometrically corrected 16-day MODIS hyper-temporal NDVI images of 250 meters resolution, from 2000 to 2009, were stacked in one composite image and classified with the ISODATA unsupervised classification algorithm. Original values were scaled to values from 0-250 corresponding to NDVI range from -0.25 to 1. The vegetation sampling scheme (as explained in 2.5.1) was also based on those NDVI classes. The initial 65 classes were also grouped in 12 groups based on similarities in the responses of their spectral signatures (Appendix I) (Taheri, 2010). The specificities of the variable are also listed in Appendix B.

2.4.4. Climatological variables

A dataset of two climatological variables (total precipitation and mean temperature) was downloaded from WorldClim (WorldClim, 2011) for the months of interest (September, October and November). The dataset represents climate grids with one square kilometre spatial resolution. More specifically the current conditions dataset was used which consists of interpolations of observed data, representative of the years from 1950 to 2000. Total precipitation and mean temperature of autumn months were averaged from the corresponding mean monthly grid layers (in Raster Calculator, ArcMap 10), in order to keep the model more parsimonious by adding 2 predictors instead of 6.

In addition, a solar radiation model was built in ArcMap 10, which stands as a measure of the total amount of incoming solar radiation (direct and diffused) based on the number of hours each pixel sees the sun per day depending on latitude, study period, and the shading effects of the nearby topography, which was derived from the DEM (Poole, et al., 2009). The dates specified in the calculation were for the modelling study period (autumn), from 1st of September to 30th of November. The three climatological parameters are listed in Appendix B.

2.5. Interviews

During the two visits in the SNP, interviews were held with personnel (rangers, firemen, and specialized mountain rescuers). Also during the vegetation sampling there were chances of interviews with shepherds and villagers living at the foothills of the mountain range.

Questions concerned the duration of the Capricorn’s mating season, practices of domestic goat’s management and especially the period and duration of seasonal movements of free grazing herds. Locations of activity were confirmed with the mountaineering maps (Anavasi, 2006) handed out. Palatability of species that were already sampled in the SNP was also discussed there with the personnel.

2.6. Vegetation classification

2.6.1. Vegetation sampling scheme

The distinction of plants to species level using the NDVI or remote sensing is frequently very difficult even with data with sufficient high spectral and spatial resolution, because many groups of plants present similar NDVI values (Pettorelli, et al., 2005). Thus, in order to examine how the vegetation structure and floristics contribute to Capricorn occurrences in the NDVI classes of the study area, a stratified random sampling scheme was applied on the dataset of MODIS hyper temporal NDVI classes (as described in 2.4.3.) to create a sampling scheme map for the fieldwork. Due to accessibility and safety issues because of the mountainous nature of the study area, only accessible areas were included. A 100 meter buffer for asphalt roads and 50 meters for safe hiking trails (with the SNP included) were intersected with the NDVI classes. In addition all agricultural and built – up areas were removed, based on the Corine land cover map (EEA, 2000), as unsuitable areas for the Capricorn. From the initial 65 classes, this approach resulted in 24 accessible classes.

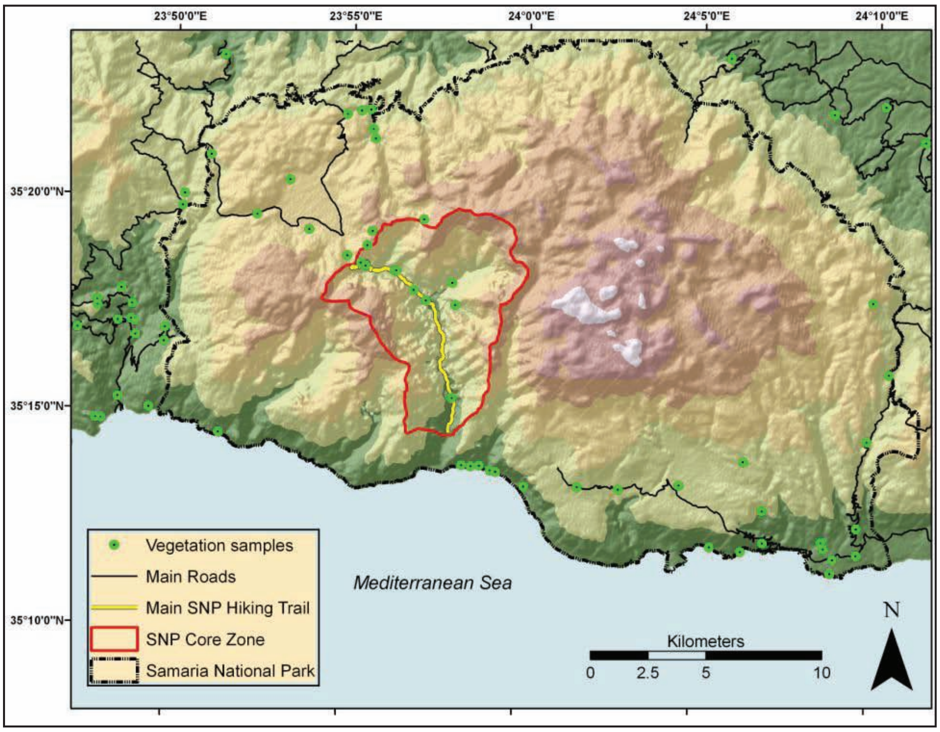

Figure 2.6: Distribution of vegetation sampling locations.

2.6.2. Vegetation sampling

Based on the sampling scheme created, 62 sites (15 m radius plot size) were visited during fieldwork. The cover percentages of plants, stones, litter and bare soils, as well as the species present in each sample, were recorded in the releve sheets (Appendix C). In addition vegetation cover was visually estimated and divided to trees, high shrubs (>0,5m high), low shrubs (<0,5m high), herbs and grasses.

One of each plant species was collected for its further identification in the herbarium of the Mediterranean Agronomical Institute of Chania (MAICh). Furthermore, their palatability was assessed by a member of the Natural History Museum of Crete (NHMC) (Appendix F). Finally, 6 more samples from the same study area were added from a previous student that followed the same process during the same month, September (Zabalaga, 2008). In total there are 2 to 5 samples for each of the 24 main NDVI classes, as some classes had 2 to 3 pixels only in the study area and others were inaccessible due to fences.

2.6.3. Classification with TWINSPAN

To identify the prevailing vegetation types in the 68 sampling sites, the vegetation data was analyzed using TWINSPAN (two-way indicator species analysis). It is one of the most frequently used methods in community ecology (Jongman et al., 1995; Pierre. Legendre et al., 1998) as a numerical method for classification of vegetation that belongs to similar groups.

Briefly, TWINSPAN's function is to divide the samples into groups by repeated dichotomization, which is then repeated for the species (M. O. Hill et al., 2005). To model differential species (i.e. species with clear ecological preferences), which is qualitative, with abundance or cover percent values as input, which is quantitative, TWINSPAN uses '*pseudospecies'* as a quantitative equivalent (M. O. Hill, et al., 2005). These are dummy variables, which correspond to relative abundance levels. For example if the cut levels follow the Braun –Blanquet scale (0-4%, 5-25%, 26-50%, 51-75%, 76-100%), a species with 18% cover at a sampled site will fill the first and second pseudospecies vectors with "1" (=presence) (Pierre. Legendre, et al., 1998).

First the data was entered in JUICE 6.5 (Tichy et al., 2006), an application for editing, classification and analysis of large phytosociological tables. The TWINSPAN algorithm was run, using the default pseudospecies cut levels (Braun–Blanquet scale), while the default maximum number of division levels was lowered from six to four, to create a smaller number of groups and aid interpretation of the results.

2.7. Home Range analysis

2.7.1. HR and temporal autocorrelation

At present, Kernel Density Estimates (KDE) are the most popular statistical method to characterize and visualize animal home ranges (Kie, et al., 2010). An assumption in this method concerning data collection, is the assumption of temporal independence of locations (Mabry, et al., 2010). Lack of independence among observations increase the probability of a type I error, by inflating the degrees of freedom (P. Legendre, 1993). Traditionally, achieving a lack of temporal autocorrelation between the locations of successive points was considered a main goal of data collection for home range studies. More recently, it has been realized that temporal independence is not necessary for most studies (Mabry, et al., 2010). Animal behaviour is almost always temporally autocorrelated, and such observations will reveal more relevant behavioral information than independent observations would (Boyce et al., 2010). Eliminating autocorellation utilizing destructive sub-sampling or restrictive sub-sampling has been shown to weaken kernel density based home range models, while maximizing number of observations using constant time intervals, as is the case in the present study, increases the accuracy and precision of their estimates (De Solla et al., 1999).

2.7.2. Kernel Density Estimators (KDE)

KDEs allow for the determination of the animal's relative use of different areas within the home range by estimating the intensity (or probability) of use at particular locations, which is the utilization distribution (Mabry, et al., 2010). The method begins by centering a bivariate probability density function with unit volume (i.e., the kernel) over each recorded point. A regular grid is then superimposed on the data and a probability density estimate is calculated at each grid intersection by summing the overlapping volumes of the kernels. A bivariate kernel probability density estimator (the utilization distribution) is then calculated over the entire grid using the probability density estimates at each grid intersection. (Rodgers et al., 2011) The resulting kernel probability density estimator will have relatively large values in areas with many observations and low values in areas with few (Seaman et al., 1996; Worton, 1989). The 95% of locations is often implemented in KDE to estimate the home range area, while the most intensely used 50% of locations are used to estimate core areas (Grassman et al., 2005; Mabry, et al., 2010).

The choice of using fixed kernels or adaptive kernels is of less importance compared to the choice of the appropriate smoothing parameter *h* (or bandwidth), which is the most significant issue in kernel analysis (Kie, et al., 2010). It effects the determination of the outer contours (home range estimate), and to a lesser extent, the estimation of the utilization distribution (Seaman, et al., 1996). No single best method of choosing a bandwidth exists (Worton, 1989). A reference bandwidth may be calculated (Worton, 1989), however for clustered animal locations, such as in the present study, the reference bandwidth will be too large, the data calculated by it over-smoothed and the areal estimate too large (Kie, et al., 2010).

Having numerous clustered locations can also be an issue for two more commonly methods used in bandwidth calculation, the least-squares cross-validation (LSCV) and the biased cross-validation (BCV), as these locations can have a disproportionately large influence on the overall estimate of their underlying functions for calculating *h* (Rodgers, et al., 2011). Furthermore, the reference and two cross-validation methods do not always produce utilization distributions with continuous outer isopleths from which to estimate the area of a home range (Rodgers, et al., 2011), as would better serve the objectives of the present study.

As an alternative, Berger and Gesse (2007) suggested to incrementally decrease the proportion of the reference bandwidth associated with individual data sets until the outermost isopleths breaks down to determine a home range estimator. Although not fully automated, the process is repeatable and therefore valid in a scientific sense (Rodgers, et al., 2011).

The latter method was applied using the Home Range Tools extension (Rodgers et al., 2007) for ArcGIS 9 (ESRI), to calculate 9 home range estimations, one for each of the 3 animals and 3 study periods. The 3 study periods were defined by separating the GPS dataset based on the mating season (15/10/2011–15/11/2011), to pre-mating (14/7/2011-14/10/2011) and post-mating (16/11/2011-02/12/2011) and by using all data available so far.

2.8. Association of Home Ranges and Vegetation Groups

First, a chi-square test between the classified vegetation groups from the TWINSPAN output and the individual MODIS hyper-temporal NDVI classes will show if there is a statistically significant association between them. If not, the aggregated grouped NDVI classes will also be tested.

If an association between them is established then the 9 Capricorn HR's will be overlaid with the NDVI classes in ArcMap 10 and the proportion of their contribution will be calculated. Thereafter, based in the proportion of each vegetation group in the NDVI classes, these two steps will be combined, resulting in the contributing proportion of vegetation groups to each of the 9 Capricorn home ranges.

2.9. Species distribution modelling with Maximum Entropy

2.9.1. Multicollinearity diagnoses

Multicollinearity is used to denote the presence of linear or near linear relationship among the explanatory variables (Silvey, 1969). In practice, in a species distribution model, the effect in how the probability of occurrence of a species is influenced by the explanatory variables, may not be determined if two or more of them are strongly correlated (Jongman, et al., 1995). A frequently used method to detect multicollinearity is by calculating the Variance Inflation Factors (VIF):

$$VIF = \frac{1}{1 - R^2} \qquad (3)$$

Myers (1990) suggests that a VIF greater than 10 indicates the presence of multicollinearity. This is commonly used as a rule of thumb to keep only independent variables in the model. Initially 3 variables, mean temperature, total precipitation and altitude, had VIF values higher than 10. The highest collinear variable was removed and the process was repeated.

2.9.2. Maximum Entropy modelling and model evaluation

The present research must be the first to apply species distribution modelling for the two target species in Crete while compiling a database of Capricorn occurrences from different sources. The mountainous nature of the study area makes formal, systematic biological surveys where presence and absence are recorded difficult to apply. Thus only presence data was available.

MaxEnt is a presence only method which utilizes a statistical mechanics approach called maximum entropy to make predictions from incomplete information (Hernandez et al., 2008). MaxEnt was chosen as the modelling method because it gives effective predictions of species spatial distributions from presence only data, for its ability to handle categorical data, and because it has shown that it often gives better results than traditional modelling methods (Phillips et al., 2006). Furthermore, when compared in a poorly studied mountainous area to other modelling approaches (Mahalanobis Typicalities and Random Forests), it also performed better especially when few presence only data was available, as is the current case for the Capricorn dataset (n=27) (Hernandez, et al., 2008).

Briefly, Maxent compares and minimizes the relative entropy between two probability densities defined in covariate space, one estimated from the presence data and one from the background data (i.e. pseudo-absences) (Elith et al., 2011). It uses six feature classes as an expanded set of transformations of the original variables. The Maxent fitted function is usually defined over many features, which means that in most models there will be more features than variables. Maxent gives a logistic output as its default, which is an attempt to get as close as to an estimate of the probability that the species is present (Elith, et al., 2011).

All the independent variables were used in the model. In order to evaluate the models performance, ideally an independent test data set of presences should be used. However, this was not available in the present study due to the samples originating from different sources, with unequal sizes and representing largely different sampling effort and methods (e.g. helicopter survey). Thus, the species data was split to a training and test partition and the model replicated 10 times. These steps were followed for both target species and the average of the 10 replicate runs was used for further analysis.

Concerning the settings, the random seed option was used which creates a different train/test partition for each run and a different random subset of the default 10,000 background points. The sampling technique used was cross validation, where samples are divided into replicate folds and each sample is used in turn for test data.

The variables importance to the model were assessed with the Jackknife test from Maxent which evaluates the relative strength of each predictor variable (Yost et al., 2008). A threshold-independent method, the area under the ROC curve (AUC), was used for the model evaluation. The ROC is a plot of the true positive fraction against one minus the specificity (which is equivalent to the false-positive fraction) for all possible thresholds. It is a measure of model success because a curve that maximizes true positive predictions and minimizes false positive predictions will have AUC values approaching 1.0, which considered an excellent model, while a model with an AUC close to 0.5 would be considered no better than random (Hernandez, et al., 2008).

2.10. Detection of potential contact zones

The Maxent logistic outputs for the two target species were imported in GIS environment and converted to raster format. In order to be turned from probability maps to binary maps denoting presence or absence of the target species a threshold must be used. No "golden rule" has emerged for this task (Liu et al., 2005; Phillips, et al., 2006). It has been shown though that subjective approaches based on an arbitrary threshold, e.g. manually set to 0.5 or with a 95% specificity were inferior to most others, while the "equal sensitivity and specificity" threshold was described among those well performing (Liu, et al., 2005). This threshold is calculated by minimizing the absolute difference between computed sensitivity and specificity.

The raster binary maps were clipped from the complete extent of the study area, to the area were the Capricorn is known to occur, based on the helicopter survey by the SNP Management Body that focused on the Core Zone of the SNP and the very steep and isolated gorges west to it (Klados and Tripiti, Fig. 2.5).

Finally, the clipped binary maps were multiplied and the size of overlapping areas calculated. The resulting map indicated contact zones between the two Capra species.

2.11. Assumptions and sources of error

All GPS recorded data, including the screened telemetry data, is assumed to have accuracy within 10 meters. For elevation, accuracies are typically lower, as much as 50 m plus or minus (Longley et al., 2005). There is a positional uncertainty of 100 meters in locations acquired from the helicopter survey, however, as described above (in 2.3.3) usually more than one Capricorn was observed, thus these occurrences indicate used sites. This is strengthened by the ecologically sound hypotheses that due to the Capricorns excellent climbing abilities, no part of the mountain range should be physically inaccessible to them.

Spatial autocorrelation can be a consideration in habitat modelling because the scale of sampling can determine whether the extent of variation in a predictor variable is actually captured (Fieberg et al., 2010). In particular, spatial data collected by radiotelemetry are autocorrelated because of the structure of underlying topography, geology, soils, hydrology and vegetation (Boyce, et al., 2010). To avoid this effect in the present research only three Capricorn occurrences were selected from the GPS-dataset. One occurrence was randomly selected from each animal from their HR's during early November, in order to represent the peak of the mating season. These 3 presences were combined with the 19 helicopter and 5 fieldwork observations, for a total of 27 Capricorn locations as an input to the modelling.

Finally, regardless of the size of a potential overlap between the habitat suitability maps of the two target species, it will only be an indicator of contact zones, as temporally the occurrences cover three months and not only the mating season.

3. Results

3.1. Interviews

All interviewee's agreed that hybridization phenomena are one-sided, with only the male Capricorns being able to mate with female domestic goats. On the other hand the female Capricorns will always avoid the male domestic goats during the rut of the later, as they can easily outrun and avoid them if they approach them or chase them. Therefore, they hybridization is avoided in the Capricorn population, with no hybrids being born there. Hybrid kids which may be born in a domestic goat herd will frequently showcase a more feral or "wild" behaviour, often straying from the herd and causing difficulty to the herders in their attempt to recapture them. This means that for the purpose of examining hybridization phenomena only the mating season of the Capricorn is meaningful. It remains possible though to have hybridization at 2nd degree, from hybrid kids from domestic female mothers that then mate with Capricorn females, however, in practise this would be very difficult to further examine. During the interviews in the SNP, it was confirmed by the park rangers that the Capricorns mating season lasts from middle of October to middle of November. This common knowledge comes to agreement with the two studies about the ecology and behaviour of the Capricorn that were conducted in one of the islets (Thodorou, 850 m of the northwest shore of Crete) were it was introduced (Husband, et al., 1984; Nicholson, et al., 1992). The start of the mating season is also the reason why the SNP is no more open to visitors after mid-October. For the 2011 season, 15th of October was also the official closing date.

Concerning the movements of the domestic goats, they could be broadly described in two practices, which in reality may be combined. Firstly, there are herds that stay in proximity to the road network (Fig 1.2), especially when near or between settlements. Though they are also free ranging, they are occasionally fed by the shepherds with commercial or additional feed even during the summer – autumn season. Majority of the domestic goat occurrences recorded during fieldwork (Fig. 2.4) belonged to that category. Secondly, there are free-grazing herds that are actively moved by the shepherds from the villages at the foothills of the mountains to the alpine pasture and grazing lands and then left to graze freely. Occurrences recorded from the helicopter survey belonged to that category. Some other locations with notable activity of free ranging herds are in the steep coastal south slopes of the mountain chain, especially when close to the ending of gorges that form streams and torrents during spring and vegetation nearby is relatively rich. From interviewee's was indentified that the seasonal movement activity lasts (also depending to the altitude of the grazing lands location) from early in the summer until late autumn - early winter, at latest when the first snowfalls start. In autumn of 2011 snowfalls were reported at the Kallergi mountain refuge (1650 m., next to the north boundaries of CZ) in the 16th of November and were considered early. As the mating season of the Capricorn starts in mid-October, there is considerable evidence based on the interviews that a temporal overlap between the two target species in parts of the mountain range during that season is possible.

3.2. GPS telemetry data screening

The initial 6591 GPS fixes cover the period from the 14th of July until the 2nd of December. Missing data (N/A) from the three GPS collars is 12.5%. Using the criteria described previously results in keeping 62.3% of the original fixes. This is substantially less than the 97% of raw data kept in a similar study in a mountainous area when the same data screening criteria were met (Poole, et al., 2009). A reason for this is that GPS radio-telemetry results have been demonstrated to be affected from factors that can make a difference in the amount of available sky. Such factors are steep slopes and canopy closure (D'Eon, et al., 2005; Frair, et al., 2004), which coexist in the SNP CZ. This is enhanced by the fact that the 3 tagged Capricorns mostly stay in the bottom of the gorge instead of areas higher in the mountains were clear sky would be more available.

3.3. Home Range analysis

Based in the remaining accurate GPS fixes, 9 home ranges were calculated in total, one for each of the 3 animals and 3 study periods. Fixed-KDE's with proportions of h reference (0.6-1) were used and the most appropriate in each of the 9 home range estimations depending on the sample size and spatial pattern of locations was kept (Kie, et al., 2010; Poole, et al., 2009). The results of the home range analysis (Table 3.1) are presented in hectares (ha), as the HR sizes were too small to be reported in km^2 (e.g., pre-mating season of the old female (CF1) is 0,004 km^2). The hectare is one of the non-SI units accepted for use with the SI units. Figures 3.1-3.3 display the maps of the home ranges for the three study periods. Home range size comparisons are from the 95% KDE.

Table 3.1: HR's of collared Capricorns for the three study periods, using 95% and 50% Fixed – KDE's, SNP, Crete, Greece.

			KDE (ha)	
Study Period	**Identification Code**	**Locations (n)**	**95%**	**50%**
Pre-mating (14/7/2011 - 14/10/2011)	CM1	895	22.7	3.9
	CF1	954	4.6	0.4
	CF2	846	15.3	1.6
Mating (15/10/2011 – 15/11/2011)	CM1	347	294.5	67.1
	CF1	386	52.1	4.8
	CF2	254	44.7	8.5
Post-mating (16/11/2011 – 02/12/2011)	CM1	182	90.3	10.3
	CF1	202	48.5	2.1
	CF2	39	69.9	17.8

The male Capricorn's (CM1, captured in RA Samaria) mating season home range is 13 times larger compared to the pre-mating and 3.3 larger than the post-mating (Table 3.1). The old female's (CF1, also RA Samaria) mating season home range is 11.4 times larger compared to its pre-mating but has practically the same extent compared to the post-mating period.

Mating season home range of the young female (CF2, north capture location) is roughly 3 times larger than for the pre-mating but, rather surprisingly, 1.5 time smaller compared to the post mating. However this result should be interpreted with caution, as due to accessibility issues in SNP in winter, post mating period data for CF2 (Fig 3.3) were only available until 21/11/2011, resulting in a smaller locations sample size compared to the other two animals from only 6 days (Table 3.1).

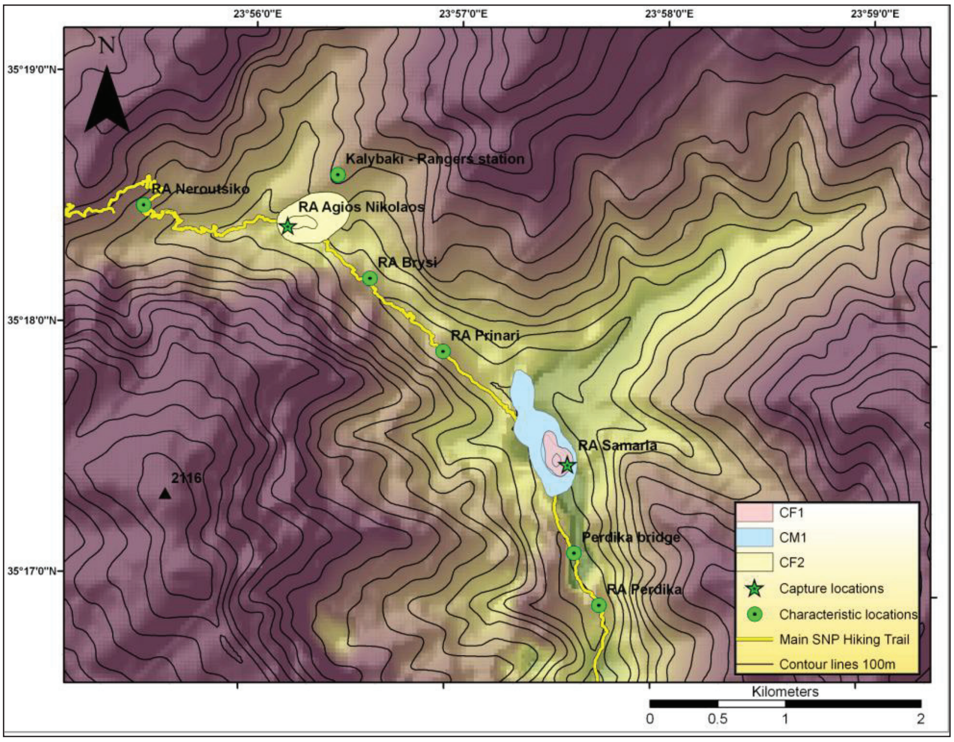

Figure 3.1: Pre-mating season map of HR's (95% and 50% Fixed-KDE).

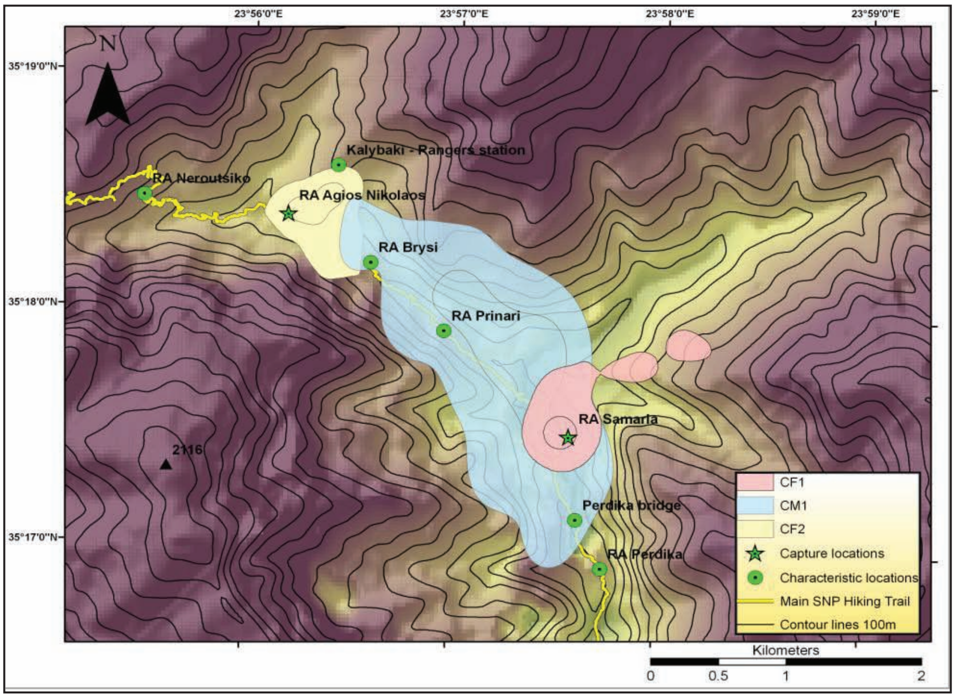

Figure 3.2: Mating season map of HR's (95% and 50% Fixed-KDE).

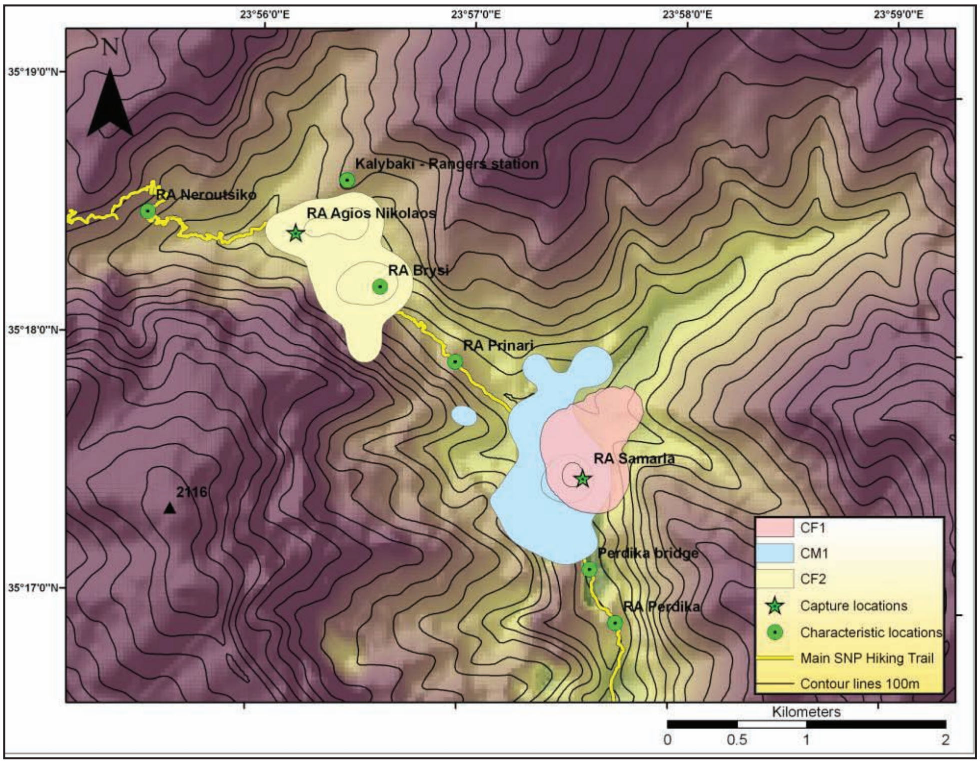

Figure 3.3: Post - mating season map of HR's (95% and 50% Fixed-KDE's).

Figure 3.1 shows that the home range of CF1 (the old female) completely overlaps that of CM1 during the pre-mating study period, in fact it almost coincides with its 50% utilization distribution. The young female (CF2) has the centre of its activity (the 50% utilization distribution) next to the capture location, the RA Agios Nikolaos. During the mating season (Fig.3.2) the male impressively increases its activity and its home range reaches almost the RA Agios Nikolaos to the northwest and the RA Perdika to the south. It is also the only time when a tagged Capricorn from one capture location has a partial HR overlap with a Capricorn from the other capture location, as it happens for CF2 and CM1. The extent of this overlap is 7.4 ha, which is 16.5% of CF2's range for that period. Overlap between CM1 and CF1 is roughly 38 ha, or 73% of CF1's home range for that period. However the direction of CM1's home range is to the northwest (to the other capture location and along the hiking trail and the dry river bottom), while for CF1 the direction is to the east-northeast where she climbs a ridge from 350 m to 1000 m. In fact 6 GPS fixes (from early November, peak of mating season) that were not included in the

HR estimation, where at even higher location nearby, with CF1 reaching up to 1300 m. The young female (CF2) also does not show high activity along the gorge bottom, but moves more to both north (900 m) and south directions (700 m). To the north she reaches the location Kalybaki (Fig.3.2), a ranger's station seldom used as it is relatively far from the main trail.

In the post-mating study period (Fig. 3.3), the old female still shows activity to the same eastern ridge, while the male has some activity to a steep ridge to the west (shown as a separate polygon in the map), and to the northeast (a new direction) along the smooth river bottom of the eastern sub-gorge. The young female shows activity to some very steep slopes south of rest area Brysi. However as already mentioned, data for this HR estimation covers 10 days less compared to the other two. It should be overall emphasized that, due to time constraints in the present study, the present data for the post-mating period do not represent an ecologically meaningful period of study but were only displayed and briefly analyzed as a first indicator of the Capricorns activity during winter.

3.4. Vegetation classification

In the 68 sampled sites (figure 2.4) a total of 67 species were identified, which represented 39 families. The largest families included Labiatae (Lamiaceae)(n=10), Fagaceae (n=3), Leguminosae (Fabaceae) (n=3), and Liliaceae (n=3). Trees constituted about 24% of the recorded species, while the woody perennials, the high shrubs and mini-shrubs, were 24% and 40% respectively. Herbs and grasses constituted about 12% of the recorded species. Average altitude in plot sites was 461 m and average number of species in a plot was 6. The mean vegetation structure covers for the sampling sites are given in table 3.1.

Table 3.2: Mean vegetation structure cover of the sampling sites.

Tree cover (%)	30%
High shrubs (>0,5m) (%)	9%
Mini-shrubs (0-0,5m) (%)	28%
Herbs (%)	2%
Grass (%)	7%

Based on the floristic composition of the sampled sites, the TWINSPAN classification resulted in 5 site groups (Table 3.2), which will be referred hereafter as structural vegetation groups, which describe the vegetation in landscape level. Thus, due to the limited amount of samples and the large spatial heterogeneity in the broader study area, the vegetation groups are dealt in a general way. From the initial 68 samples, 65 were satisfactory classified to structural vegetation groups. The other 3 were from a higher altitude zone, at around 1400m, with small tree cover and moderate shrub cover, which were classified separately but were not considered enough to form a group. Average number of samples per vegetation group is 13 and their range 10 to 16. From the initial 67 species, 27 have frequent enough presences in order to be classified in 11 meaningful plant communities, named after the dominant species or those that were distinctly important in a group of sites (Vogiatzakis, et al., 2003). Plant communities contain from 1 up to 4 species. The complete list of the plant species used in the table is in Appendix E. To summarize the classification result to a synoptic table some groups of the resulting table were moved to make neighboring groups as similar as possible, so transitions between the groups could be observed (Pierre. Legendre, et al., 1998).

Table 3.3: Synoptic table summarizing the vegetation classification

		STRUCTURAL VEGETATION GROUPS				
		A	**B**	**C**	**D**	**E**
	Number of releves	*13*	*10*	*16*	*10*	*16*
Plant Communities	*Pistacia lentiscus*	—				
	Pinus brutia	━	━		—	
	Cupressus sempervirens		━	━	- - -	
	Quercus coccifera		- - -	░	- - -	
	Olea europaea europea				━	
	Sarcopoterium spinosum	- - -	- - -	—	░	░
	Thymus capitatus	—	- - -			—
	Phlomis fruticosa		- - -	—	—	- - -
	Satureja thymbra	- - -	—	- - -		- - -
	Genista acanthoclada					- - -
	Berberis cretica			- - -		

------- Presence between 5 -20%

—— Presence between 20 - 50%

══ Presence between 50 – 80%

▬▬ Presence above 80%

The average number of highly palatable species is also reported in the group description. Palatability is assumed to be the same for Capricorns and domestic goats. Plants palatability was described by a member of the NHMC in five classes; Palatable, Thorny, Bristles or lint, Chemical substances or Scent, and Toxic. In areas with available palatable species those should be preferred and the toxic always avoided, however for the other 3 classes palatability depends on availability or not of the more palatable species. For example, in a study in the islet Thodorou, (which is only 68 ha thus foraging resources are limited) where Capricorns were introduced and foraging preferences were studied, the thorny *Calicotome villosa* was among the highly palatable species (Papadopoulos, 2002). The full list for all the species identified in the field is in Appendix F.

3.4.1. Structural Vegetation Groups

The distribution of the 5 structural vegetation groups to the broader study area is shown in Figure 3.4. All groups had presence of the very common thorny low shrub *Sarcopoterium spinosum* which is commonly avoided by all herbivores of the island. A more thorough description of each group follows.

Group A: *Pinus brutia – Pistacia lentiscus* vegetation group, referred to in the text as the *Pinus – Pistacia* group. This group represents Pine forest mixed with high shrubs maquia vegetation, as the *Pistacia lentiscus* often forms very dense shrubs reaching up to 3 meters. The altitude varies at the sampling sites from 25 to 270m, with the average being 86m, which is the lowest between the groups. Samples are mostly located in coastal areas with south aspect of varying steepness. Average tree height is 10 m with a tree cover of 35.4%, while cover of high shrubs is 14.8% and of mini-shrubs 21%. Presence of the *Pistacia lentiscus* community, which includes the Carob tree (*Ceratonia siliqua*) is exclusive to this group. Most consistent low shrub community is the *Thymus capitatus.* Average number of highly palatable species is 1.

Group B: *Cupressus sempervirens - Pinus brutia* vegetation group, (hereafter the *Cupressus – Pinus* group). This structural vegetation group is transitional between groups A and C, as it represents mature coniferous forest of Pine mixed with Cypress. Altitude at sampling sites varies between 165 and 1150 m, with the average being 578 m. Average tree height is 17 m, with a tree cover of 45.5% (both the highest among all the groups). Cover of high shrubs is relatively low with 5% and of mini-shrubs 25%, the later often located at canopy openings in the Pine forest. Most consistent low shrub community is the *Satureja thymbra.* Average number of highly palatable species is 2.

Group C: *Cupressus sempervirens - Quercus coccifera* vegetation group (hereafter the *Cupressus – Quercus* group). This group represents mixed forest of evergreen (*Cupressus sempervirens*, *Quercus coccifera*), semi-evergreen (*Acer sempervirens*) and deciduous trees (*Platanus orientalis*). Sample locations are all in SNP with several in the Core Zone (Fig. 3.4), while their altitude varies between 200 and 1430 m. Average altitude is 831m, the highest between the 5 groups. Average tree height is 13 m and tree cover 38%, while cover of high shrubs is 14% and of mini-shrubs 25%. It is the only group with presence of the Cretan barberry (*Berberis cretica*), which grows over 800m. Most consistent low shrub community is the *Phlomis fruticosa.* Average number of highly palatable species is 3. Two of those usually in every sample were the two distinctly important species for this group, the Cypress and Kemes Oak.

Group D: *Olea europaea europea - Pinus brutia* vegetation group, hereafter referred as *Olea – Pinus* group. This group describes old and abandoned olive groves in semi-natural areas, in proximity to or mixed with other common trees, such as Pine and Kermes Oak. Olive trees are exclusive to this group. Sampling sites are between 155 and 550 m, in average 369m. Average tree height is 9 m, with a tree cover of 37%, while the covers of high shrubs and mini-shrubs are 10% and 23% respectively. Most consistent low shrub community is the *Sarcopoterium spinosum.* Average number of highly palatable species is 3.

Group E: *Sarcopoterium spinosum* vegetation group. This group broadly represents the phrygana mini-shrubs. Sampling sites were located mostly in the Sfakia region to the southeast, exposed to south facing slopes, and in an altitude between 15 and 1040masl (380m average). The lowest average tree height and tree cover were recorded in this group (2.5 m and 5% respectively). Mini-shrubs had the highest cover between the groups with 40%, while high shrubs had the lowest with 3%. The other mini-shrubs communities represented in the group are the *Thymus capitatus, Phlomis fruticosa, Satureja thymbra,* and *Genista acanthoclada*. Average number of highly palatable species was 1.

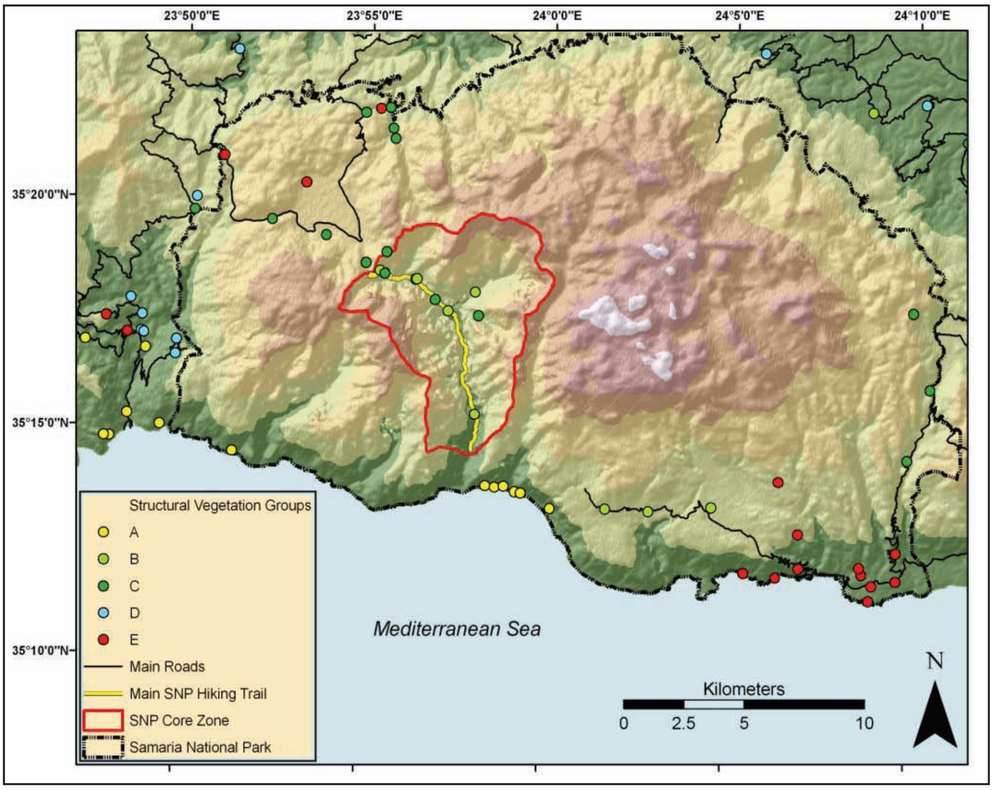

Figure 3.4: Distribution of the 5 structural vegetation groups in the broader study area; altitude zones as in figure 2.2.

3.5. Association of Structural Vegetation Groups and MODIS hyper-temporal NDVI classes

By cross-tabulating the 24 individual MODIS hyper-temporal NDVI classes and the number of observations from each of the structural vegetation groups that they included, it was clear that no statistically significant association could be drawn, as few NDVI classes were exclusive to vegetation groups. However, by using the aggregated grouped NDVI classes, a chi-square test, (Table 3.4, $\chi^2 = 41.3$, d.f. = 28, $P < 0.001$) shows a statistically significant association between them, thus they were used for further analysis in relation to the home ranges and as a categorical variable input to the distribution model.

Table 3.4: Cross-tabulation of Structural Vegetation Groups on Grouped NDVI classes

OBSERVED VALUES	***Structural Vegetation Group***					
Grouped NDVI classes	***A***	***B***	***C***	***D***	***E***	**Total**
4	2	2	3	0	0	7
5	3	3	0	9	2	17
6	1	3	5	1	0	10
7	4	0	0	0	1	5
8	0	0	1	0	1	2
10	3	1	7	0	1	12
11	0	1	0	0	9	10
12	0	0	0	0	2	2
Total	13	10	16	10	16	65

It should be noted that as the sampling was not based on the aggregated grouped NDVI classes they were not all represented but only 8 out of 12 were. This happened as due to accessibility issues certain areas had to be removed from the sampling scheme of the initial individual NDVI classes as well. For example, areas for group 9 were roughly from 1500-2000m and for group 2 over 2000m, while groups 1 and 3 were mostly in steep inaccessible south facing slopes over the sea. However the groups 5, 6 and 10, which are most important for the analysis (Fig.3.6, 3.8, 3.10), are well represented with 17, 10, and 12 samples respectively (Table 3.4), as they were included in the 50 m buffer along the main SNP hiking trail. These NDVI classes intersect to a large extent with the 9 estimated home ranges as well (Fig.3.1-3.3).

3.5.1. Association of HR's and Structural Vegetation Groups

As described in section 2.8, the percentile contribution of the grouped NDVI classes to the each of the 9 Capricorn home ranges was calculated in (Fig.3.5, 3.7, 3.9). Thereafter, based in Table 3.4, the proportion of each vegetation group in the grouped NDVI classes was also calculated (Table 3.5). Finally, these two steps were combined, resulting in the percentile proportion of vegetation groups to each of the 9 Capricorn home ranges (Fig.3.6, 3.8, 3.10).

Table 3.5: Proportion of Vegetation Groups in sampled Grouped NDVI classes

% of Vegetation Groups in NDVI group	***Vegetation Group***					
Grouped NDVI classes	***A***	***B***	***C***	***D***	***E***	**Sum%**
4	29	29	43	0	0	100
5	18	18	0	53	12	100
6	10	30	50	10	0	100
7	80	0	0	0	20	100
8	0	0	50	0	50	100
10	25	8	58	0	8	100
11	0	10	0	0	90	100
12	0	0	0	0	100	100

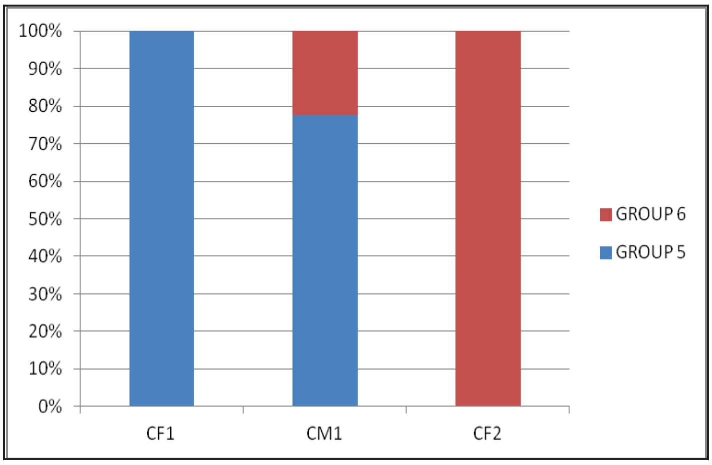

Figure 3.5: Pre-mating season, proportion of Grouped NDVI classes to Capricorn HR's.

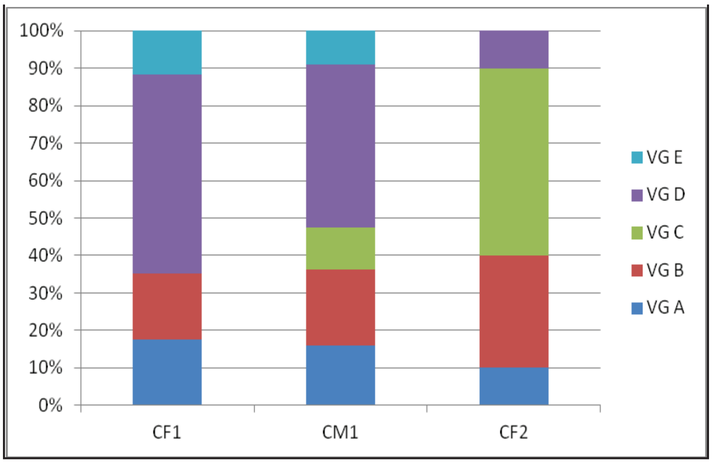

Figure 3.6: Pre-mating season, proportion of Vegetation Groups to Capricorn HR's.

As the pre-mating season home ranges were the smallest ones, only 2 grouped NDVI classes contributed (Fig 3.5). For the old female Capricorn (CF1) vegetation group D (*Olea – Pinus* group) has a 53% contribution and group B (*Cupressus – Pinus*) a 17% (Fig 3.6). For the young female (CF2) vegetation group C (*Cupressus – Quercus*) has also a 50% contribution and group B has 30% (Fig 3.6). For the male's HR (CM1), group D (*Olea – Pinus* group) contributed 43% and group B (*Cupressus – Pinus*) 20% (Fig 3.6).

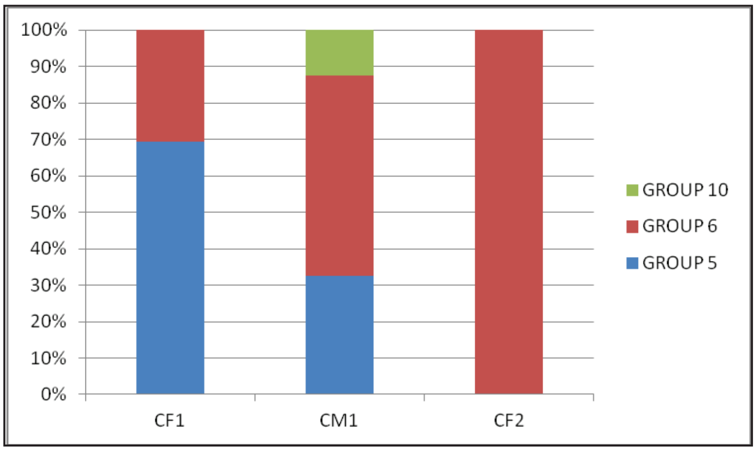

Figure 3.7: Mating season, proportion of Grouped NDVI classes to Capricorn HR's.

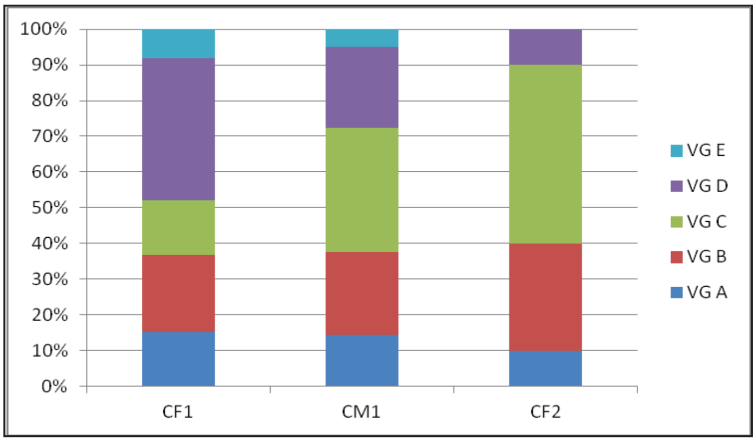

Figure 3.8: Mating season, proportion of Vegetation Groups to Capricorn HR's.

NDVI class 10 is added to the mating season analysis of the male Capricorn (Fig 3.7), covering 12% of the size of its home range for that season (Fig 3.2). This class is associated with the *Cupressus – Quercus* group C, which increased by 25% compared to the previous season. For the old female Capricorn (CF1) vegetation group D (*Olea-Pinus)* remains the highest with a 40% contribution, however it dropped by 13% compared to previous period (Fig 3.8). Group C is new with a 13% contribution. For the young female (CF2), even though its home range size tripled compared to pre-mating season, still only NDVI class 6 contributes (Fig 3.7), thus interpretation is the same as for the previous season. For the male's HR, group C (*Cupressus – Quercus*) contributed 35%, group B (*Cupressus – Pinus*) 23%, and group D (*Olea – Pinus*) also 23% (Fig 3.8).

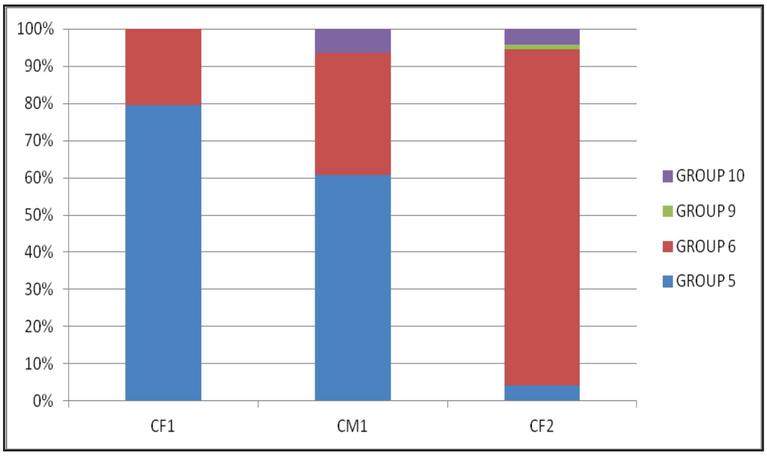

Figure 3.9: Post-mating season, proportion of Grouped NDVI classes to Capricorn HR's.

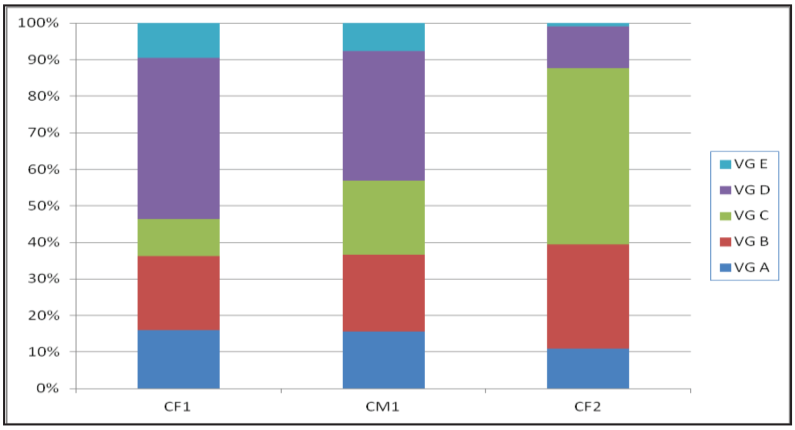

Figure 3.10: Post-mating season, proportion of Vegetation Groups to Capricorn HR's.

Note that one more NDVI class is added to the post- mating season analysis of CF2, class 9 (Fig 3.9). It has not been sampled, however its contribution is only 1.4% and exclusive to CF2, whose home range analysis for this period covers only 5 days. Otherwise, for CF2, group C (*Cupressus – Quercus*) contributes by 48% and group B (*Cupressus*

– *Pinus*) 28%. For the old female Capricorn (CF1), vegetation group D (*Olea – Pinus*) remains the highest with a 44% contribution, followed by group B (*Cupressus – Pinus*) with 21% (Fig 3.8). For the male's home range, group D contributes 36%, group B (*Cupressus – Pinus*) 21%, and group C (*Cupressus – Quercus*) 20% (Fig 3.10).

3.6. Distribution modelling

This section presents the final independent predictors used for the modelling and the outputs from the distribution modelling of the two target species with Maxent.

3.6.1. Independent predictors

A multicollinearity test was performed to the preliminary 11 continuous predictors (as described in 2.8.1). Finally, two variables (mean temperature, total precipitation) were removed from the modelling process, as they showed to be highly correlated to altitude in the study area. The remaining 9 independent continuous variables (Table 3.6), plus the 2 categorical ones (land cover and grouped NDVI classes) were used for the distribution modelling of the 2 target species.

Table 3.6: Final VIF values of independent continuous predictors.

Predictor variables	***VIF***
Solar Radiation	1.2
Slope	1.4
Northing	1.5
Easting	2.3
Distance to Settlements	4.2
Distance to Rivers and Streams	1.2
Distance to Roads	3.1
Distance to Escape Route	1.3
Altitude	2.8

3.6.2. Distribution modelling of the Cretan Capricorn

The final dataset of Capricorn occurrences comprised of a total of 27 locations; 19 from the helicopter survey, 5 from fieldwork observations, and 3 from the mating season of the tracked animals. Following the methodology described in section 2.8.2, the results of the 10 replicate runs are presented. Figure 3.12 shows the distribution map together with the 27 Capricorn locations. Note that instead of using only the area monitored by the helicopter survey, the extent the whole study area was used in the environmental parameters to train the model in order to identify all potentially suitable areas.

The Jackknife test of training gain variable importance (Fig 3.11) shows that the most important variable when used in isolation is distance to settlements, followed closely by the distance to roads and distance to escape route. Distance to settlements decreased the gain most when excluded from the model, followed by northing and distance to settlements.

The response curves (Fig 3.13, complete at Appendix G) show how the probability of presence changes as each environmental variable is varied, keeping all other environmental variables at their average sample value. The mean response of the 10 replicate Maxent runs are in red and the mean +/- one standard deviation in blue with two shades for the categorical variables. For the distance to settlements probability of occurrence shows a positive response, peaking at 0.7 ata distance of 6 km and showing a large range in the standard deviations after that point. As expected, probability of occurrence has also a positive response to the distance to roads, up to 0.95. Northing shows no response to presence probability except for a steep drop for the north aspect. An explanation to this is that slopes with north direction at the north front of Capricorn distribution are directly exposed to the settlements and roads to the north part of the Chania prefecture. Altitude has the maximum probability of occurrence from around 400 m (roughly RA Samaria) to 1500 m (approximate tree line). Distance to escape route has a steep negative response, with a probability approaching 0 when in distance of 1500 m from steep slopes.

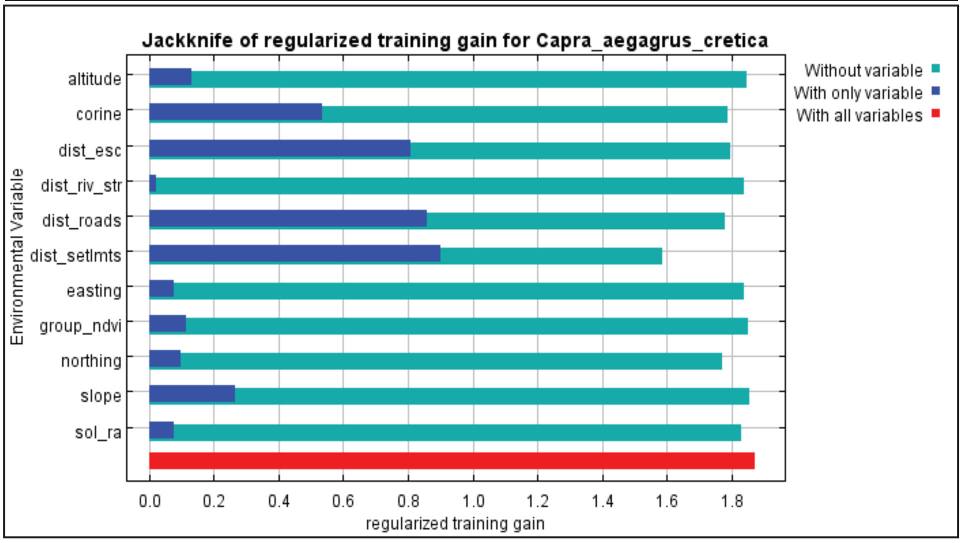

Figure 3.11: Jackknife test of training gain variable importance for Domestic Goat distribution model.

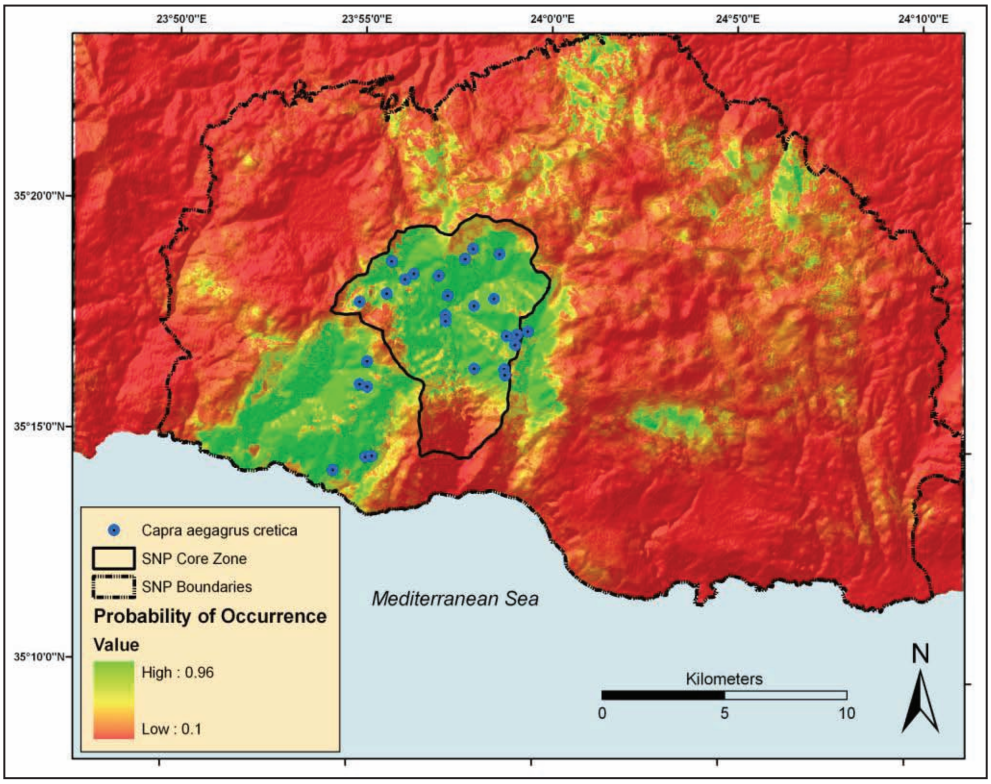

Figure 3.12: Probability of occurrence of the Cretan Capricorn overlaid with the 27 actual presences.

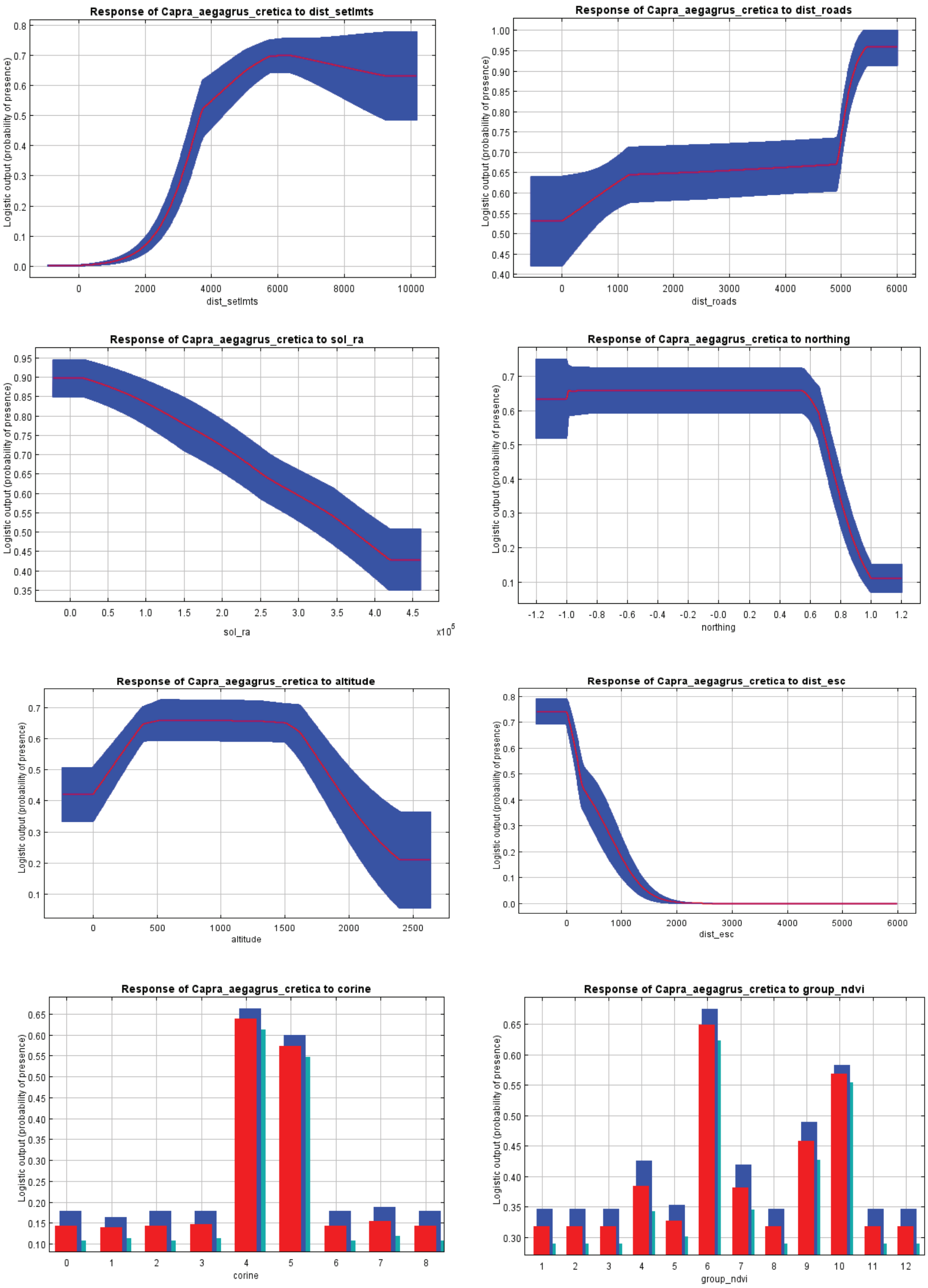

Figure 3.13: Response curves of most important environmental variables to probability of occurrence of Capricorn.

Response to solar radiation (WH/m^2) is linear negative, and as the modelled radiation apart from the actual dates of the study period also takes into account topography, (thus summits and areas in higher altitudes in general have more incoming radiation and less shading from surrounding summits), this means that Capricorns avoid exposed and open parts of the mountain range, which again comes to agreement with the cryptic nature of the animal. For better interpretation of the 2 categorical variables, as they are both related to the vegetation cover directly (NDVI groups) or indirectly (land cover classes), their bars are shown from a model created using only one of them each time. For the land cover classes, only classes 4 (Transitional woodland-shrub) and 5 (Coniferous forest) contribute to the model and give a probability of occurrence 0.63 and 0.58 respectively. For the grouped NDVI classes, the classes 6 and 10 give the highest probability of occurrence with 0.65 and 0.56 respectively.

In general, these results are consistent with expectations on the ecology and behaviour of the Cretan Capricorn. Finally, the average test AUC for the 10 replicate runs may be considered high at 0.896 and the standard deviation is 0.051 (Appendix E).

3.6.3. Distribution modelling of the Domestic Goat

The final dataset of domestic goat occurrences included 88 occurrences; 75 from fieldwork and 13 from the helicopter survey. Figure 3.14 shows the distribution map together with the 88 domestic goat observations used to train the model. Importance of the distance to the road network is evident by inspecting the map, however as biased as the result may seem it is consistent with the practices described in the interviews section and observations made during fieldwork. Areas with high probability of occurrence also appear inside and in proximity to the SNP Core Zone.

Importance of the distance to roads parameter is confirmed by the Jackknife test of training gain variable importance (Fig 3.15), followed by the distance to escape route and altitude. Three response curves are strongly negative to the probability of the domestic goat occurrence, distance to roads, distance to escape route and altitude (Fig 3.16, complete at Appendix G). For the distance to roads, minimizing the distance gives a probability of occurrence of 0.7. Distance to escape route follows the same pattern, with a maximum probability of 0.68.

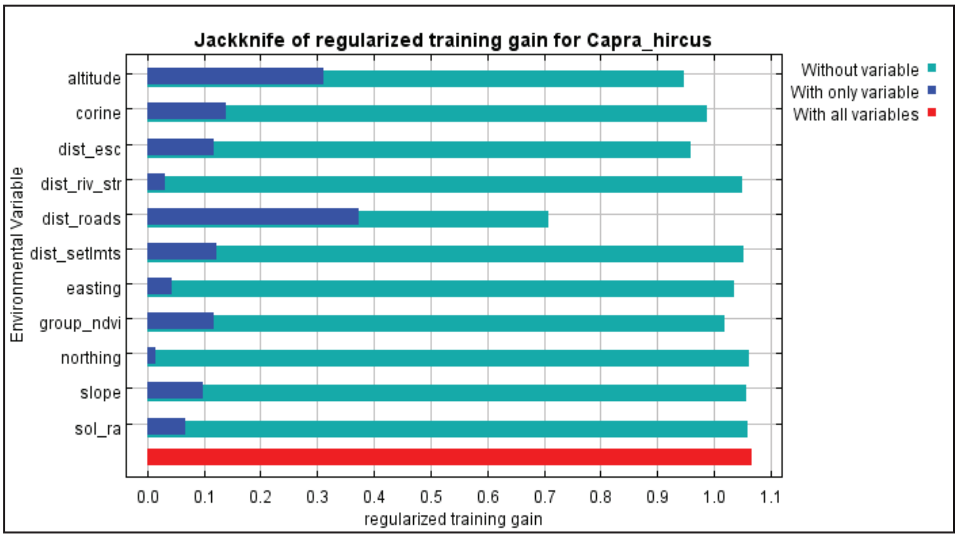

Figure 3.15: Jackknife test of training gain variable importance for Domestic Goat distribution model.

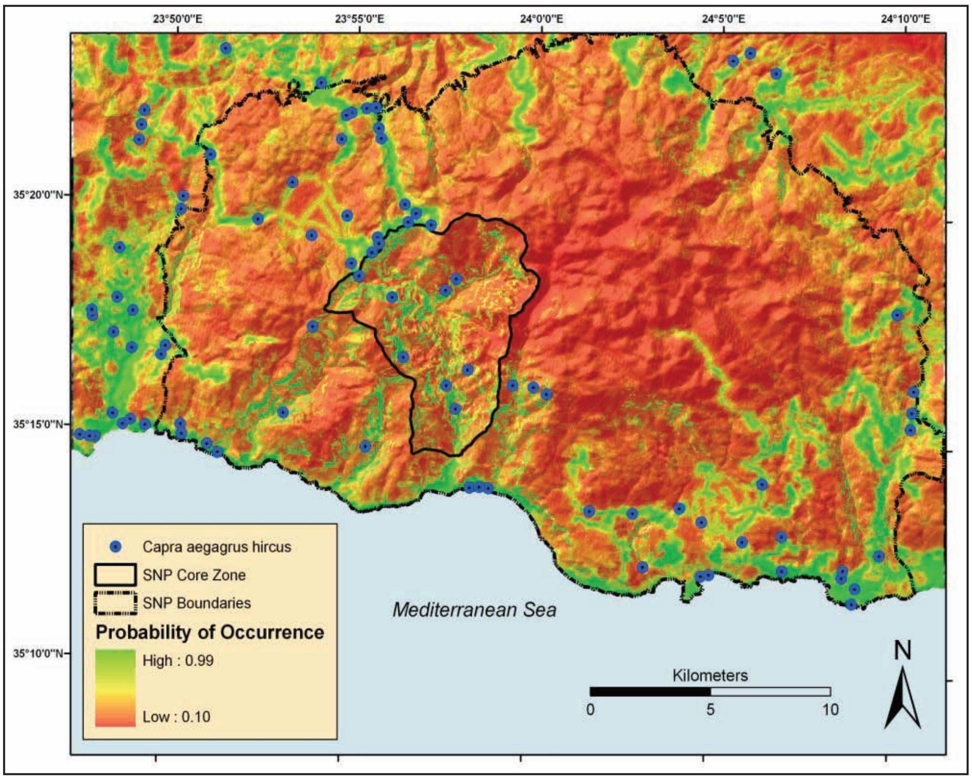

Figure 3.14: Probability of occurrence of Domestic Goat overlaid with the 88 actual presences.

Note that this variable was included to the model even though the domestic goats should not have any predators, the variable stills accounts for their favourability to areas close to steep slopes.

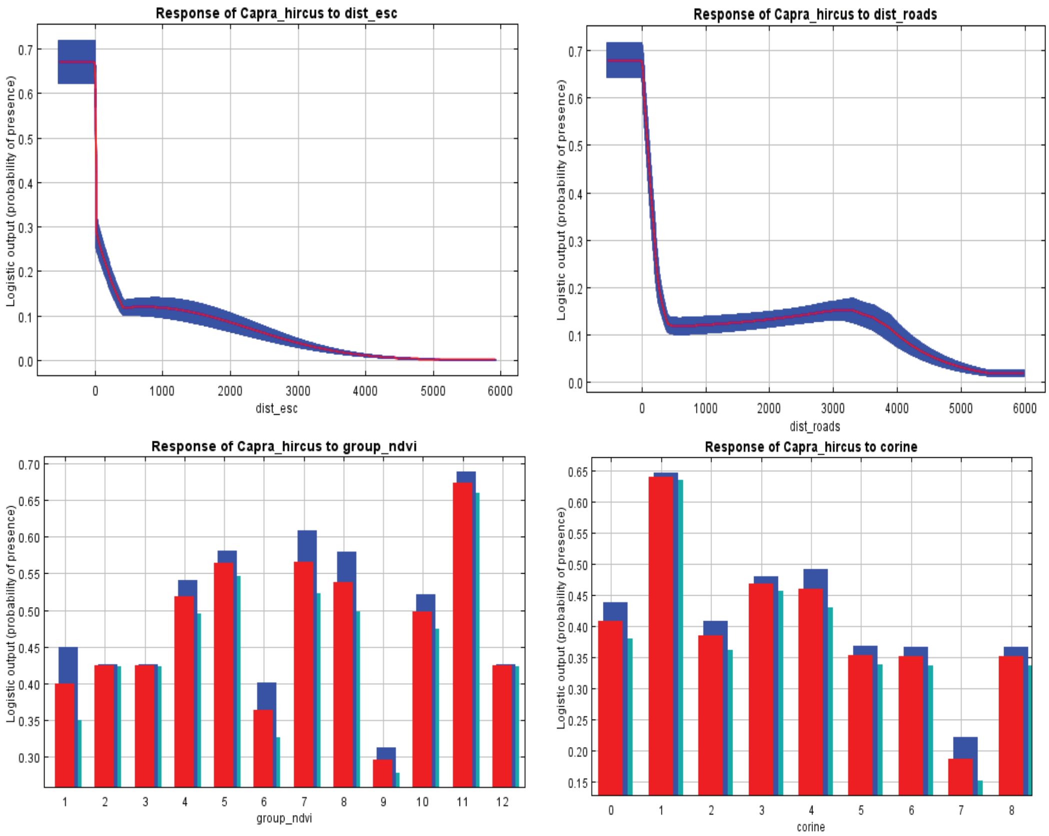

Figure 3.16: Response curves of most important environmental variables to probability of occurrence of Domestic goat.

A model created using only the land cover map shows that the most important category is class 1, which represents the sclerophyllous low shrub phrygana vegetation, followed by classes 3 (natural grasslands) and 4 (transitional woodland-shrub). It seems a realistic result as these areas cover a large part of the lower altitude zone (0-500 m) of the mountain range were many domestic goat sightings were recorded during fieldwork. Importance of the mini-shrub phrygana vegetation is confirmed from the grouped NDVI class 11, which has the highest probability (0.67), with 90% of its observations belonging to the low shrub *Sarcopoterium* group (vegetation group E, Table 3.5). This also further indicates that there is some collinerarity between the 2 categorical variables. Finally, the average test AUC for the 10 replicate runs is 0.843 (Appendix E), and the standard deviation is 0.034. It is somewhat lower compared to the Capricorn's, as perhaps expected for a more generalist species but still can be considered satisfactory high.

3.7. Potential Contact Zones

Following the process described in section 2.9 and using the equal sensitivity and specificity threshold (which was 0.32 for the Capricorn and 0.34 for the domestic goat) resulted in the habitat suitability maps for the two target species (Fig.3.17, 3.18).

The binary habitat suitability map of the Capricorn (Fig. 3.18), indicates suitable areas in green colour and unsuitable areas in red. Based in the area monitored in the helicopter survey, it overall appears realistic as it includes these areas, namely the SNP Core Zone, especially the part north of the RA Samaria, the Klados and Tripiti gorges to the west and the Eligia gorge to the east (also in Fig. 3.19 in detail). Note how bare summits and ridges above the tree line are excluded, such as those across the west border of the CZ. It is also interesting that very small patches far from the known range appear to the north and the east part of the mountain range where no Capricorn sighting was recorded. One area though that seems as an over prediction of the model is the coastal part south of the steep Klados and Tripiti gorges, as it seems unlikely that Capricorns would approach so close to sea level. Actually there are very steep cliffs there (<40˚), and as proximity to those was an important modelling parameter the calculated probability from Maxent was higher than the threshold. The binary habitat suitability map of domestic goats (Fig. 3.17) also appears overall realistic. However some areas could be considered as under predicted, namely the areas in the altitude zone around 1000 -1300 m close to the centre of the mountain range and east of the SNP CZ where herding activity was also mentioned during fieldwork. This occurred because no presence locations could be recorded in those parts during fieldwork.

Figure 3.19 shows a map with the potential contact zones for autumn in the actual area of interest for the Capricorn, based on the extent of the area studied in the helicopter survey. Total size of overlapping areas is 8.1 km². The overlap in the SNP CZ is 3.6 km², which is 7.4 % of the Core Zones size. The rest 4.47 km² are in other areas in the periphery of the CZ; the Eligia Gorge to the east, the Klados and Tripiti Gorges to the west and in the Poria location to the north.

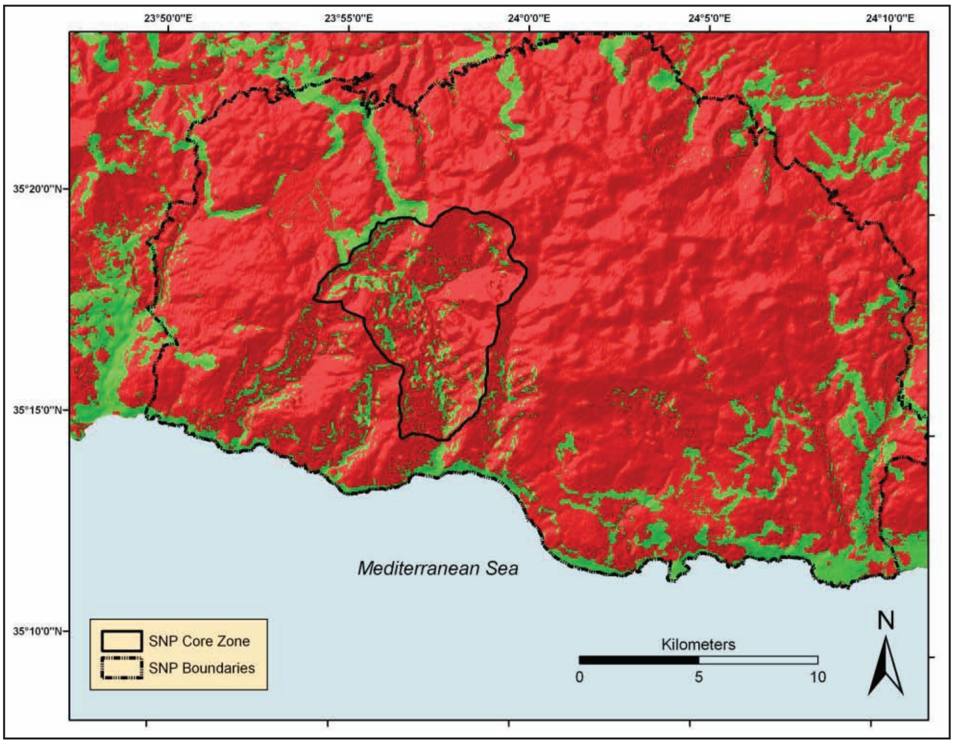

Figure 3.18: Domestic goat habitat suitability map.

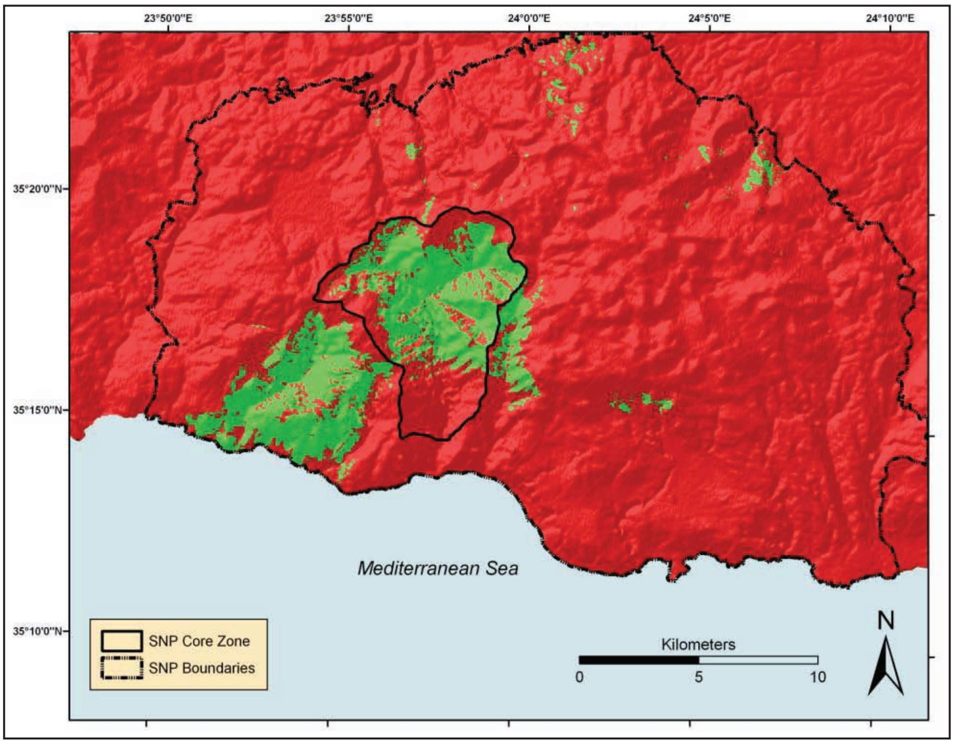

Figure 3.17: Cretan Capricorn habitat suitability map.

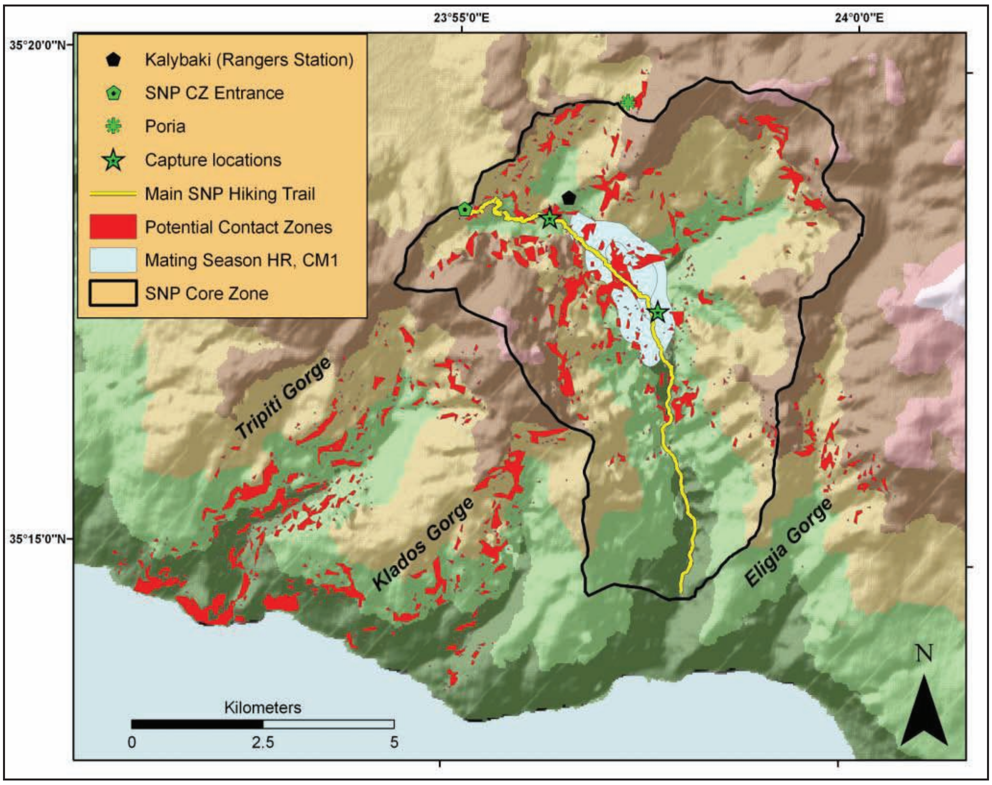

Figure 3.19: Potential Contact Zones for autumn, altitude zones as in Fig. 2.2

The mating season home range of the male Capricorn (as in Fig.3.2) is also shown. Overlap between HR of CM1 and potential contact zones is 0.53 km^2 (or 18% of its size) for the 95% KDE and 0.20 km^2 (or 30% of its size) for the 50% KDE.

Some characteristic point locations were also added to Figure 3.19 in order to raise some conservation and management implications in the next chapter.

4. Discussion

4.1. Distribution at population scale

Scale and extent of a study area are always an important issue to consider in species distribution modelling (Franklin et al., 2010). Distribution modelling at a small scale such as in the present study (36 x 22 km extent) can reveal environmental predictors that best characterise habitat at population level (Patthey, 2003). Overall, for modeling at small spatial scales and in complex topography the use of indirect variables may provide better predictions (Guisan, et al., 2000). Indirect gradients are variables that have no direct physiological relevance for a species' performance (slope, aspect, elevation), but usually replace a combination of different resources (water for animals) and direct gradients (temperature) in a simple way (Guisan et al., 1999). These indirect variables can be derived from DEM's which tend to be relatively accurate, even in mountainous terrain (Guisan, et al., 2000).

In general, the most important variables for modelling distribution of mountain ungulates in small spatial scales are derived from DEM's, such as elevation, slope, N-S and E-W aspect and distance to escape terrain (Gross, et al., 2002; Poole, et al., 2009). On the other hand, researchers modelling the distribution of an Iberian Wild Goat subspecies (*Capra pyrenaica victoriae*) in national scale in Spain, linked its distribution mostly to climate variables (high levels of rainfall and relative air humidity in July) (Acevedo et al., 2011).

In the present study, at a small scale and extent of study area, with a 30 m spatial resolution, and a temporal resolution of 3 months, the predictor variables that were expected to be the most important for the distribution of the Capricorn (distance from anthropogenic disturbance, altitude, forest land cover) did actually contribute most to its probability of occurrence. However, slope angle, which is often used as a parameter in distribution modelling in mountainous environments, was in this case of less importance compared to a parameter derived from it, the proximity to steep slopes, which had high contribution to both species because it modelled their defensive mechanism, as steep slopes are used as escape terrain. The same set of predictor variables was also used for the distribution modelling of the free-ranging domestic goats and performed sufficiently well with a slightly smaller AUC of ROC in the test model evaluation which could be expected for a generalist species.

4.2. Individual's Home Range scale

No previous study on the Cretan Capricorn has examined home ranges of individuals in order to compare the present findings. Furthermore, as explained below, the specific features of the SNP CZ and the length of the period (less than 5 months) that GPS data represents, make comparisons with relative species such as *Capra aegagrus* or *Capra ibex* difficult.

This applies especially for the pre-mating study period due to the large anthropogenic influence from the visitors, as during that time, the SNP CZ is open for the tourist season. It should be noted that this influence does not seem to count as a disturbance as it does at population level. During fieldwork a loose group of roughly 15 Capricorns was observed living in proximity to the RA Samaria and most of them seemed acquainted to human presence, the 2 collared ones being among them. Four males in the middle age class (which is roughly 4-8 y.o.) were observed, the oldest and higher in the hierarchy being 7 y.o, who was the main target for the fourth collar deployment (Fig 1.2 and Appendix D). The influence seems particularly larger at the RA Samaria where the two Capricorns captured there both showed a rather impressive increase in their home range size (13 times and 11 times larger than the pre-mating season for the male and female respectively), compared to the smaller difference for the young female captured in the other location (only 3 times larger HR compared to pre-mating period).

On the other hand, the post-mating study period was analysed as a first indicator of winter activity, however due to the small (until 2nd December) and unequal sample size of GPS fixes between individuals, the present results will not be further discussed. Perhaps with a complete dataset for winter, seasonal movements could be observed, especially for the CF2 whose HR is around the higher capture location at 650 m. This should depend on weather conditions and particularly on the magnitude of snowfalls; though it is not unusual to have snow at that altitude in the White Mountains in winter.

Concerning the Capricorns relation to the vegetation groups, in general CM1 has more intermixed groups contributing, as all his 3 HR's are larger compared to the 2 females. For the 2 Capricorns captured in RA Samaria, group D (*Olea-Pinus* group) was the most important, which might seem odd at first, having olive trees in the middle of the gorge. However exactly at this location the Samaria settlement was inhabited until 1962 (chapter 2.2) and olive groves planted from that period still exist. For the CF2, at the other capture location with 300 m higher altitude, group C first and then B contributed most; the 2 groups which are characterized by consistent Cypress presence, while the low shrubs group E was almost absent, with only 2% in one season. In fact that area is well known for some characteristic Cypresses 25 meters high and 7 meters of girth, which are considered more than 600 years of age (Papiomytoglou, 2006).

Regarding to changes between the two first study periods, contribution of the high altitude zone mixed forest group *Cupressus – Quercus* (group C, with high average tree cover at 38%), increased in the mating season for the male by 25% compared to the previous season, and for the old female by 13%. The young female, even though it tripled its HR size compared to pre-mating season, this was not translated to difference in the vegetation groups, perhaps showing a steady preference for groups C and B as well, or due to the more homogenous vegetation structure at the 1st capture location.

Overall the three most contributing structural vegetation groups (B, C, D) are the ones representing different mixed forest types, while the high and low shrub groups (A and E respectively) contribute substantially less to the Capricorns home ranges. This confirms the hypothesis based on earlier observations, that the structural vegetation groups that contribute most to the home ranges of the three collared Capricorns over the study periods represent vegetation that provides shelter.

This result comes to agreement with the distribution modelling result, thus it seems that could be generalized at population level. In particular, the Coniferous forest class was one of the two most important land cover classes. Furthermore the 2 grouped NDVI classes that gave the highest probability of occurrence in the model (classes 6 and 10 by 50% and 58% respectively) are mostly associated with the high altitude zone forest group C (*Cupressus – Quercus*). Further inspecting the spectral signatures of the two groups (Appendix I) and comparison to those of other groups showed that they have the highest average values in the 0-250 scale with smaller amplitude and fluctuations, thus they should indeed represent evergreen forest.

Concerning the sizes of the home ranges of the three collared Capricorns, they were indeed larger during the mating season compared to pre-mating season. Despite this observation, it is difficult to assess if the change between the HR's is driven by foraging patterns as would normally be expected for herbivores. There are two reasons for this, firstly, despite having preferences on "more" palatable plants, the Cretan Capricorns, as goats in general, are able to forage on a great variety of plants parts and types. Thus it seems hard to link them to a certain species, especially in an area of great flora abundance and biodiversity such as the SNP CZ.

Secondly, the main factor driving their movements in the mating season should be the need to mate by itself. Movements in this period could also be attributed to territorial behaviour. This has been observed by Husband and Davis (1984) in the Thodorou islet population where "males were observed on several occasions during the rut vigorously rubbing pine trees and shrubs with their horns and removing bark." However, this behaviour is normally attributed to males older than CM1. Another interesting observation during mating season was the almost 1000 m climb that the old female demonstrated at the peak of the mating season. As during the rut the males can chase the females for several hours while females are avoiding mounting, this lack of mounting in these chases has been hypothesized to be an example of female mate choice (Nicholson, et al., 1992). This perhaps could be a possible explanation for the female's steep climb at that particular timing.

In general concerning the annual cycle of the Capricorn, again it is the winter season, as well as early spring, that seem most likely to present more interesting patterns. These seasons include the gestation and calving periods which perhaps may add a need for different nutrients in the female's diet.

Overall, despite the clear trend in the sizes of the home ranges of the three collared Capricorns, due to the small sample size these observations cannot be statistically tested to draw population level inferences. In principal, more than 20 animals are needed to make reliable statistical inferences about comparisons between populations (Lindberg et al., 2007), whereas there have also been studies on HR size with 15 tracked animals (Jerina, 2009). This has been identified as a main issue in animal studies with GPS-telemetry in general, where this need is complicated by the high cost per GPS unit (Hebblewhite, et al., 2010).

4.3. Potential Contact Zones

Hybridization between the Capricorn and free-ranging domestic goats has long been identified as an issue for the Capricorns conservation (Sfougaris, et al., 1996) . However, to our knowledge, no research has proven or even examined if it actually occurs.

In the present study, by overlapping the habitat suitability maps for the 2 two target species, possible contact zones were identified using occurrences and climatic parameters for autumn which includes the mating season of the Capricorn. Even though the two target species had often a completely opposite response to predictors that were important to their distribution model, (e.g., the distance to roads and distance to settlements), overlapping areas in their distribution were still observed. Overlapping areas were 7.4% of the extent of SNP CZ. Contact zones in the periphery of the CZ were also identified; however these overlaps could not be tested for statistical significance. Furthermore, as the potential contact zones were based on overlaying the two binary suitability maps, these were directly depending to the choice of threshold. Thus, ideally, a sensitivity analysis over the threshold selection should also be conducted.

Another indicator for further examination of contact zones is the transitional woodland-shrubland land cover, which was shown as among the most important for the distribution of both target species. In particular, in the study area these areas are located between the coniferous forest (which was shown as the Capricorns favourite habitat) and shrublands where often domestic goats are free-grazing. This further indicates them as potential contact zones.

4.4. Conservation implications

Based on the previous findings, a measure for the conservation of the Cretan Capricorn would be to include all areas with coniferous forest that exist in the periphery of the SNP CZ as buffer zones to it.

Furthermore, during fieldwork and based on interviews, a specific area of interest as a potential contact zone in the north boundaries of the SNP CZ was inspected (Poria, 1466 m.a.s.l., Fig.3.19). It should be noted that modelled potential contact zones are also shown around this area in Figure 3.19.

This location is the second main accessible entrance to the SNP CZ from its northern side. The high number of piled droppings in the area indicated it as a site used by domestic goats (Appendix D). A rather accessible trail connects this area to certain locations in the CZ, the Kalybaki rangers station and the RA Agios Nikolaos (Fig. 3.19), which are inside or in great proximity to the HR of CF2 and CM1 during mating season. As previously stated, apart from hybridization, the other danger Capricorns are facing is poaching. As reported in a local newspaper, in the 16^{th} of November 2011 poachers were caught at Kalybaki station with 4 Capricorn carcasses (Georgakakis, 2011). As there is no ranger's station in the Poria location, a gated fence could be a solution in preventing both poachers and free ranging domestic goats from entering the SNP CZ.

Finally, based on the distribution modelling, a human induced pressure limiting the Capricorns distribution is the distance to the road network. The road network in the model included the dirt roads that are frequently used by herders to move the domestic herds. Thus, another measure for the Capricorns conservation would be not to give permission, or add very strict criterion under special circumstances, for the creation of new roads, especially in parts in proximity to the Capricorns distribution.

4.5. Limitations of the study

The number of identified species during fieldwork (67) and the average number of flora species per sample (6) could be described as low for Crete. Fieldwork was conducted from September 12^{th} to October 4^{th}. Grasses were often difficult to identify to species level as they were frequently heavily grazed or in dry condition from the hot and dry summer season, especially in locations with south aspect. There was also a small contribution of annual herbs as most flower in spring. Thus, if the purpose for the floristic composition would be to identify more species, vegetation sampling carried out in mid-spring would be more appropriate when the Mediterranean ecosystems show their highest plant diversity and are more suitable to identification purposes (Sfougaris, et al., 1996). Despite this, for the purposes of the present study, the timing of fieldwork was suitable and fitting for the temporal scale of the distribution modelling and the home range analysis. Some other limitations of the home range analysis and of the distribution modelling part were discussed above. Another important issue was the separation between domestic sheep and domestic goat observations based on the helicopter survey. Despite that it was based on an ecologically sound criterion, it still remains a proxy and not actual occurrence data.

5. Conclusions and recommendations

5.1. Conclusions

In the present research the Cretan Capricorn was studied for the first time in its natural habitat at two different scales; home ranges of individuals and distribution modelling at the extent of their population. An association between grouped hyper-temporal MODIS NDVI classes and the structural vegetation groups was established and was further used in the analysis at both scales. The home ranges of the three individual collared Capricorns were calculated from the GPS telemetry data, however despite the clear trend observed in size differences between pre-mating and mating season, drawing statistical inferences to population level about their size was not possible due to the small number of collared animals.

A distribution model using Maxent showed that the most important parameters for the Capricorn occurrence are a large distance from roads and settlements, areas in proximity to steep slopes to use as escape terrain, habitat in an altitude zone from 400 to 1500 m, and areas with coniferous forest or transitional between woodland and shrub. The most important grouped hyper-temporal NDVI classes were 6 and 10, which is consistent with the HR analysis as they were also two of the three most contributing classes in that scale. Both classes were primarily associated with the high altitude zone mixed and mainly coniferous *Cupressus – Quercus* group. The results from the two different scales come to agreement with each other about their preferred habitat and confirm general ecological knowledge on the animal that has not been previously tested.

Interviews helped identify the mating season of the Capricorn as the period when hybridization with the free-ranging domestic goats is possible as well as the seasonal patterns in domestic goat herds. Concerning the detection of contact zones, the overlapping areas between suitable habitats of the two target species were calculated for autumn, which includes the mating season of the Capricorn. More research is needed to determine the significance of this overlap and more robust occurrences off free-ranging domestic goats, are required in order to determine whether this overlap is of significant importance.

5.2. Recommendations

The possibilities for future research with the GPS telemetry database are numerous with a lot of potential for providing knowledge on the ecology and behaviour of the Cretan Capricorn and its habitat use. Recommendations for future research are summarized as follows:

At individuals home range scale:

1) Deploy the fourth available collar to an old or middle aged male Capricorn, preferably as soon as the SNP CZ opens, as before that period there are major accessibility issues in winter. Ideally, funds will be available for more GPS collar units who should be deployed, if possible, in other locations than the SNP CZ with no interactions with visitors.

2) Compare the home ranges from pre-mating and mating season with those of the winter period from upcoming data. Winter period could be defined from the end of mating season (mid-November) until the April, leaving that one month as a separate study period of calving (which is around mid-April). In 1st of May the SNP CZ opens for visitors and a new study period should start for the tourist season until October 2012. This broad period could also be split to months. Furthermore, by mid-July 2012 the GPS database will represent a whole year. Annual HR's can then be compared to seasonal ones, which might further reveal possible seasonal preferences.

3) Analyze movements and daily activity from the rich (16 fixes per day) GPS telemetry database and test hypotheses that Capricorns have higher activity (for foraging) early in the morning and late in the evening as observed in the Thodorou islet where Capricorns were introduced (Nicholson, et al., 1992). Temperature that is also recorded at each GPS fix can be added to this analysis.

4) In order to study possible nocturnal activity, study how the estimates of home range size and composition are affected by using diurnal and nocturnal GPS fixes (Jerina, 2009).

5) Periodicity in movements can also be examined by using temporal autocorrelation functions (ACF's) (Boyce, et al., 2010) .

6) Future vegetation sampling scheme based on the aggregated grouped NDVI classes included in the home ranges of the 3 individuals and especially those shown important from the distribution model (groups 6, 9 and 10) and combined with rest of analysis.

7) Couple the GPS data with remote sensing images of the actual dates.

At population scale:

1) Derive average NDVI for each corresponding study period to add as a continuous modelling parameter.

2) In order to properly test the hybridization hypotheses, higher temporal resolution of data is required only from the mating season of the Capricorn. For this purpose, ideally another helicopter survey should take place in late October/early November when mating season peaks and activity in the 3 collared individuals was shown to be higher compared to summer/pre-mating season when the 1st helicopter survey was conducted. It would also be important, if possible, to have separate observations between domestic sheep and domestic goats. This survey could further assist in estimation of the Capricorn population, as the first one already did (Limberakis, et al., 2009). As an alternative season for a helicopter survey, mid April/early May would also provide valuable insights as a period with few actual observations which also is the period of calving.

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7. Appendix

<u>Appendix A:</u> GPS-PLUS collars (VECTRONICS Aerospace Berlin, 2010) specificities.

Technical characteristics	Features
VHF Beacon Transmitter	A mortality signal, if no activity has been detected for a pre-defined time
	An emergency signal if battery power is low
GPS Plus Handheld Terminal	Internal GPS receiver and "Range Checker Mode" for finding the direction and distance to the collar and the tracked animal
	Download GPS data sets and temperature from the GPS PLUS collar
	Upload of new GPS or VHF beacon schedules to the collar
Radio and timer drop-off	Time control and additional radio control to release the collar on command if you are in range of the animal (maximum 500 meters, depending on terrain)
	Maximum lifetime of drop-off is 3 years.

Appendix B: **List of variables**

1) Continuous variables	Unit
Altitude	m
Slope	Degrees
Northing	-1 to 1(Scaled)
Easting	-1 to 1(Scaled)
Solar Radiation	WH/m^2
Autumn total precipitation	mm
Autumn mean temperature	°C x 10
Distance to settlements	m
Distance to rivers and streams	m
Distance to roads	m
Distance to escape route	m

2) CORINE Land Cover Map, Level 3 classes, reclassified

ID	Class
0	Agricultural or built-up area
1	Sclerophyllous vegetation
2	Broad-leaved forest
3	Natural grasslands
4	Transitional woodland-shrub
5	Coniferous forest
6	Bare rocks
7	Sparsely vegetated areas
8	Moors and heathland

3) MODIS hyper-temporal NDVI classes

	Date	Temporal Resolution	Spatial Resolution	Unit
MODIS hyper-temporal NDVI	18/2/2000 – 28/7/2009	16 days	250 m	0-250 (Scaled)

Appendix C: Sample sheet used during fieldwork, modified from Zabalaga (2008).

Sample sheet

General information

Date:	Sample N°	
Time:	NDVI class	/ /
	C.a.cretica	*Y / N*
X:	*C.hircus*	*Y / N*
Y:		

Exposure:		Weather conditions:
Overall unit:		

Remarks:	Natural	Seminatural	Agricultural	Humanmade

On the spot

	Cover (%)			Picture num.
Tree (m)				
Shrub (0,5- m)				
Minishrub (0-0,5m)				
Herb				
Litter				
Soil		Type:	Color:	
Stones		Type:	Color:	

Comments

Appendix D: Additional photos

Picture 1: Original capture location along the dry river bottom in SNP CZ, June 2011 (by Dr. Bert Toxopeus).

Picture 2: Female Capricorn in SNP CZ grazing under a Pine (*Pinus brutia*).

Picture 3: View to the SNP CZ from the location Poria, summits Gingilos (2080 m) and Volakias (2116 m) in the background.

Picture 4: Numerous goat droppings, location Poria.

<u>Appendix E:</u> Complete list of plant communities and dominant species

Dominant Species	Plant communities
Pistacia lentiscus	*Pistacia lentiscus*
	Ceratonia siliqua
	Lithodoria hispidula
Pinus brutia	*Pinus brutia*
Cupressus sempervirens	*Cupressus sempervirens*
Quercus coccifera	*Quercus coccifera*
	Acer sempervirens
	Platanus orientalis
Olea europaea europea	*Olea europaea europea*
Sarcopoterium spinosum	*Sarcopoterium spinosum*
	Carlina graeca
Calicotome villosa	*Calicotome villosa*
	Urginea maritima
	Thymus capitatus
	Olea europaea oleaster
Phlomis fruticosa	*Phlomis fruticosa*
	Euphorbia characias
	Verbascum spinosum
Satureja thymbra	*Satureja thymbra*
	Salvia fruticosa
	Nerium oleander
	Pteridium aquilinum
Genista acanthoclada	*Genista acanthoclada*
	Osyris alba
	Asparagus aphyllus orientali
	Ballota pseudodictamnus pseudodictamnus
Berberis cretica	*Berberis cretica*

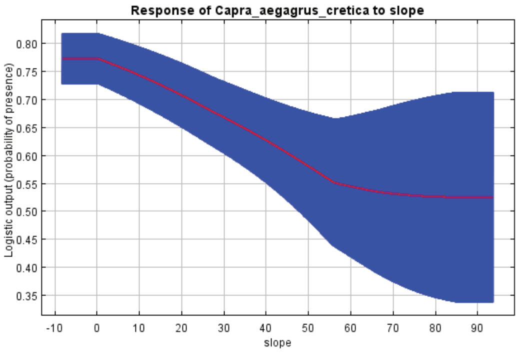
<u>Appendix F:</u> Description of palatability of sampled vegetation (prepared by Manolis Abramakis, Agriculturalist/ Botanist, NHMC), Simplified table, as more than one descriptions may aplly.

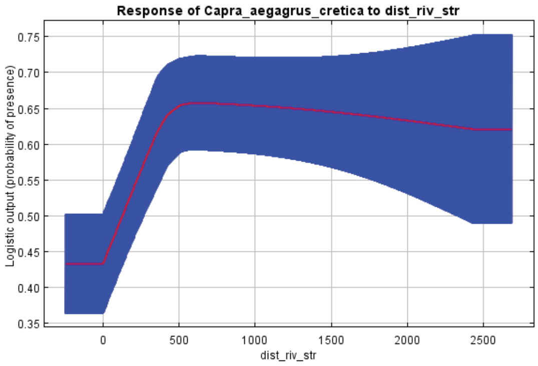
SPECIES	DESCRIPTION
Pteridium aquilinum	Palatable
Crataegus monogyna	Palatable
Cupressus sempervirens	Palatable
Quercus Coccifera	Palatable
Olea europaea europea	Palatable
Olea europaea var. oleaster (Olea oleaster)	Palatable
Piptatherum blancheanum	Palatable
Platanus orientalis	Palatable
Acer sempervirens	Palatable
Crucianella latifolia	Palatable
Ceratonia siliqua	Palatable
Pyrus spinosa (=Pyrus amygdaliformis)	Palatable
Helichrysum microphyllum	Palatable
Morus alba	Palatable
Castanea sativa	Palatable
Plantago lagopus	Palatable
Hordeum bulbosum	Palatable
Convolvulus oleifolius	Palatable
Quercus pubescens	Palatable
Hedera helix	Palatable
Ficus carica	Palatable
Heliotropium europeum	Palatable
Juglans regia L.	Palatable
Erica manipuliflora	Palatable
Euphorbia acanthothamnos	Toxic
Urginea maritima	Toxic
Nerium oleander	Toxic
Euphorbia characias	Toxic
Asphodelus ramosus	Toxic
Delphinium staphisagria	Toxic
Glaucium flavum	Toxic
Sarcopoterium spinosum	Thorny
Ononis spinosa diacantha	Thorny
Berberis cretica	Thorny
Carlina curetum	Thorny

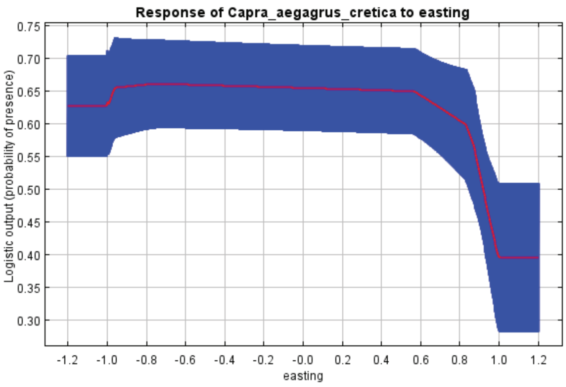
Carlina graeca	Thorny
Genista acanthoclada	Thorny
Asparagus aphyllus ssp. orientalis	Thorny
Calicotome villosa	Thorny
Rhamnus lycioides	Thorny
Caparis spinosa	Thorny
Juniperus oxycedrus oxycedrus	Thorny
Satureja thymbra	Bristles or lint
Satureja juliana	Bristles or lint
Dittrichia viscosa	Bristles or lint
Satureja calamintha	Bristles or lint
Phlomis Fruticosa	Bristles or lint
Verbascum spinosum	Bristles or lint
Phlomis lanata	Bristles or lint
Ballota pseudodicтamnus ssp. pseudodictamnus	Bristles or lint
Lithodoria hispidula	Bristles or lint
Verbascum sinuatum	Bristles or lint
Echium angustifolium	Bristles or lint
Verbascum macrurum	Bristles or lint
Pinus brutia	Chemical substances or Aromatic
Cistus creticus	Chemical substances or Aromatic
Salvia fruticosa	Chemical substances or Aromatic
Pistacia Lentiscus	Chemical substances or Aromatic
Thymus capitatus	Chemical substances or Aromatic
Origanum microphylum	Chemical substances or Aromatic
Foeniculum vulgare	Chemical substances or Aromatic
Hypericum empetrifolium empetrifolium	Chemical substances or Aromatic
Pistacia terebinthus	Chemical substances or Aromatic
Laurus nobilis	Chemical substances or Aromatic
Cistus cf salvifolius	Chemical substances or Aromatic
Osyris alba	*Uknown*

Appendix G: Response curves

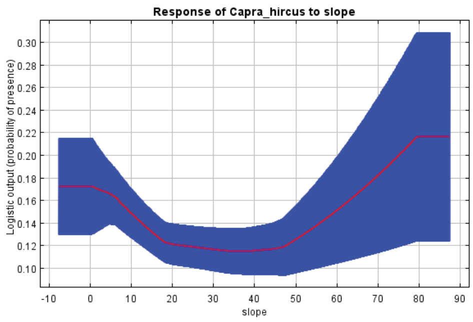
1) Rest response curves for Capricorn probability of occurrence

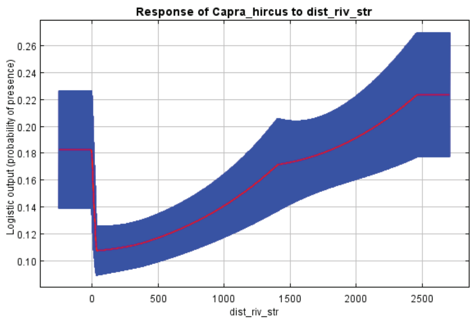


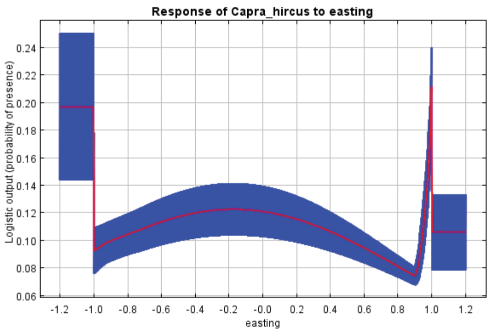


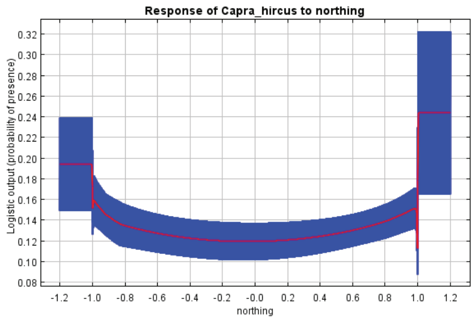


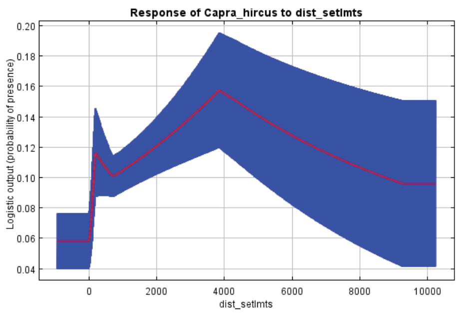
2) Response curves for domestic goat probability of occurrence

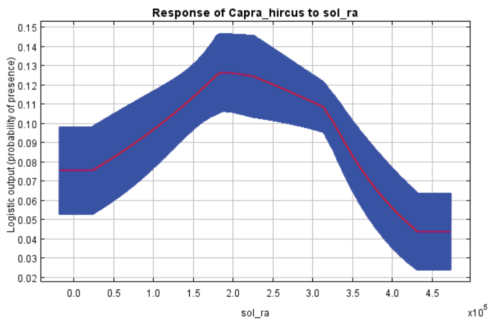


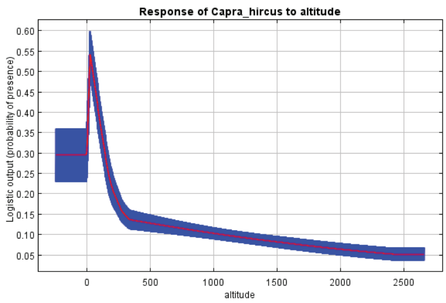




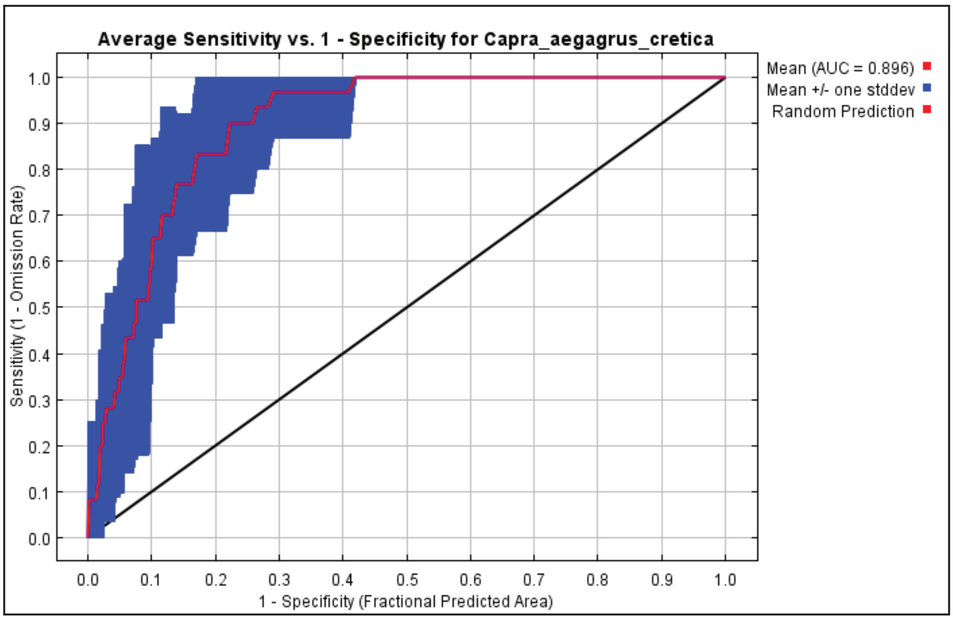


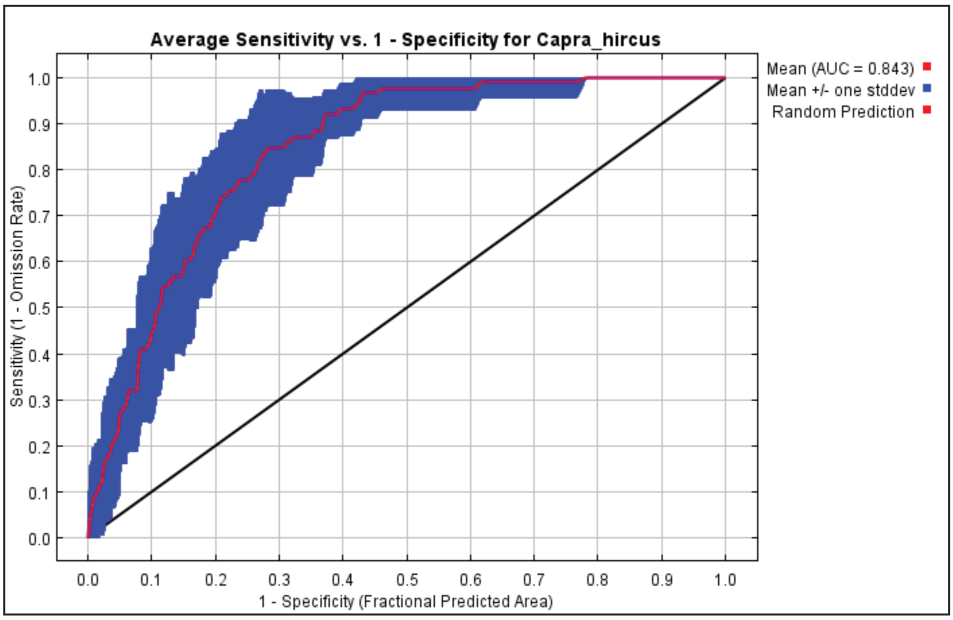






Appendix H: AUC for the two target species





<u>Appendix I:</u> Spectral signatures of grouped MODIS hyper-temporal NDVI classes, prepared by Taheri (2010). Series code indicates original individual classes.