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# Land Abandonment and Wild Ungulates: Maintaining Open Spaces in Catalan pre-Pyrenees

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## Land Abandonment and Wild Ungulates: Maintaining Open Spaces in Catalan pre-Pyrenees

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### Introduction

In the Mediterranean region, rural areas experienced land abandonment through the 1900s that has significantly changed the processes that influence landscape patterns (Acevedo et al. 2011; Cohen et al, 2011; Delibes-Mateo et al. 2009; Farina 2007; Prins and Fritz 2008; San Miguel-Ayanz, Perea-Garcia-Calvo, Fernandez-Olalla 2010; Vila 1999). Human disturbances such as clearing of the land for cultivation, pastures for domestic livestock, and timbering have decreased. The result of this land abandonment by humans leads to expansion of forest cover which reduces landscape heterogeneity (Cohen et al. 2011; Delibes-Mateo et al. 2009; Vila 1999). The reduction in landscape heterogeneity often threatens the biodiversity of the Mediterranean region as the open habitats disappear and along with them the flora and fauna that thrive in open spaces (Cohen et al. 2011; Delibes-Mateo et al. 2009; Farina 2007; Vila 1999).

Such is the case with land abandonment in a protected open space (Espai d'Interes Natural - EIN) the Alta Garrotxa in the Catalan pre-Pyrenees. After significant human depopulation of the region starting in the 1950s, forest cover has increased to the extent that it is the dominant land cover. This change in landscape processes and cover is a threat to the cultural identity and biodiversity of the region (Cohen et al. 2011; Vila et al. 2009).

The case of land abandonment in Mediterranean regions presents challenges for development of management approaches. The issue at hand is what is the reference landscape that should be the goal of management and restoration activities? The idea that Europe's "...natural vegetation was a closed canopy forest is probably not correct" (Vera, Bakker and Olf 2008 194). Another researcher, Robin Gill (2006 171) states that "historically the word 'forest' in Europe referred to places containing herbivores and trees, and in places may have resembled parkland or savanna more than closed-canopy woodland." There is an indication that closed-canopy forest is not the reference landscape of Mediterranean regions.

There are those that argue that the reference landscape of Mediterranean regions is a cultural landscape created by extensive domestic livestock systems (Farina 2007; San Miguel-Ayanz et al. 2010). As the domestic livestock systems contract with land abandonment, researchers suggest that there is the potential for native wild ungulates to replace domestic livestock in maintenance of patchy Mediterranean landscapes (San Miguel-Ayanz et al. 2010).

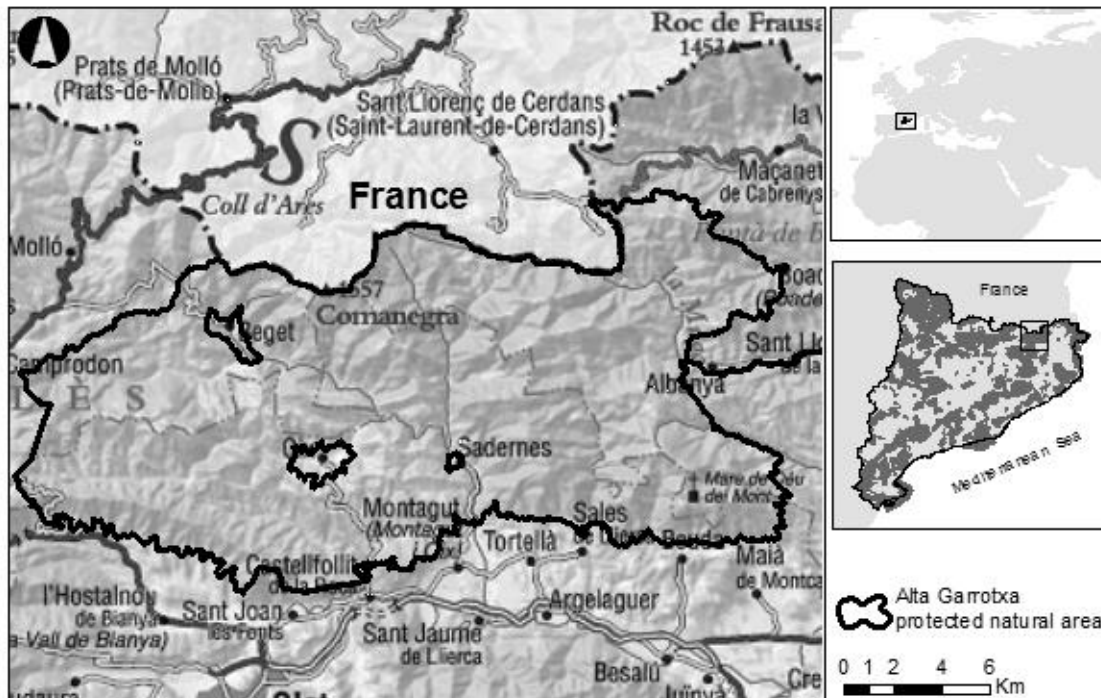
This also represents an opportunity for ‘rewilding’ of an abandoned landscape. The arguments in favor of rewilding an abandoned landscape include the stability of a diverse ecosystem in the maintenance of landscapes. The native, wild ungulates in combination with a top-level predator in conjunction with human hunting would guarantee maintenance of the landscape and an increase in biodiversity (Soule and Noss 1998). In Europe, researchers argue that the former agricultural landscapes did not provide for an adequate quality of life for humans, and that rewilding presents a more sustainable use of steep, Mediterranean landscapes (Navarro and Pereira 2012).

The objective of this research is to evaluate recent trends and the current population of native ungulates in the Alta Garrotxa for potential to maintain landscape heterogeneity. We hypothesize that with coordinated management of ungulates through hunting policies and promotion of a top level predator, the wolf (*Canis lupus*), native ungulates of Alta Garrotxa could achieve densities sufficient to maintain landscape heterogeneity through browsing.

### Study Area

Alta Garrotxa is located in the Pre-Pyrenees of north central Catalunya in northeast Spain. It is an area that has been designated as a Space of Natural Interest (Espai d’interès natural – EIN) by the Generalitat de Catalunya in 1992. This is a designation similar to the International Union for Conservation of Nature’s Category VI: Managed Resource Protected Area. An update of the accord in 1998 determined its current boundary and size of 32,865 ha.

Figure 1: map of study area



It is a region with a varied surface geology and topography the combination of which creates a heterogeneous pattern of habitats and microclimates. Most of the study area has calcareous surface geology which lends itself to karst processes with caves that Neanderthals used in the late Pleistocene (Vila 1999). There are granitic, gneiss, siliceous and other acidic substrates that contribute to different soils and plant communities (Vila 1999).

The forest communities on the calcareous soils include those dominated by holly oaks (*Quercus ilex*) and beech (*Fagus sylvatica*). On the siliceous soils, there are pubescent oak groves (*Quercus humilis*) and chestnut (*Castanea sativa*). There are also Scots pine (*Pinus sylvestris*) forests (Vila 1999).

Pollen analysis results (82,000 ybp) indicate that prehistoric forests included beech, fir (*Abies* spp.), and pine with holly oaks and other oak species. Human use of the forests began around 200 B.C. with wood harvested for boat building, and cleared for cultivation and pastures. Intense use of the forests continued into the modern age with demand for good wood to build boats promulgating forest conservation and silviculture development in Alta Garrotxa. Iron metal forges in the region relied on wood for fuel. Charcoal production, metal smithing and railroad ties along with agricultural uses left Alta Garrotxa completely denuded until the 1950s (Vila 1999).

In the mid 20<sup>th</sup> century, charcoal is replaced by butane, and industrial employment in the surrounding valleys contributes to a loss of traditional economic activities in Alta Garrotxa such as charcoal production and small-scale agriculture. Figures 2 and 3 depict charcoal production and the cultural landscape of this region in the early 1900s. Population in Alta Garrotxa decreased by 85% from 1950-1990 (Cohen et al. 2011; Vila 1999). There has been a slight increase in population since that time related particularly to tourism and recreational activities such as hiking and rock climbing. These activities have had negligible influence on the evolution of the landscape that continues the rapid process of homogenization founded in the progressive increase of the forest matrix.

Figure 2. Charcoal production in Alta Garrotxa in early 1900s (Archives, Generalitat de Catalunya)



Figure 3. Open Landscapes of Alta Garrotxa, Taleixa 1950 (Francesc Vidal, Archive, Comarcal de la Garrotxa)



In 1957, analysis of aerial photographs showed that roughly 30% of the land area was used as pasture with some field cropping, and by 2003 that had declined to less than 8% (Cohen et al. 2010). With land abandonment, pastures and cultivated fields are quickly succeeding to woody species with over 70% of the land cover as closed canopy forest by 1991. Holly oak (27%) is the largest forest type, followed by oak (13%), pine (12%) indeterminate (9%), beech (8%) and riparian (1%). The forests are young and diameter at breast height (dbh) is uniformly small which lends itself to very high stem density (Vila 1999). Figure 4 is a recent photograph of Taleixa which shows the expansion of forest cover.

Figure 4. Expansion of Forest Cover in Taleixa, Alta Garrotxa (Josep Vila 2012)



Animals that have evolved in this landscape for centuries along with humans depend on the open pastures and woodlands as primary habitat. Loss of open habitat threatens the biodiversity of Alta Garrotxa. The transition to woody thickets and forests favors large mammals over small and leads to the decline of species such as the European wild rabbit (*Oryctolagus cuniculus*), Iberian hare (*Lepus granatensis*), red legged partridge (*Alectoris rufa*), woodpigeon (*Columba palumbus*), turtle dove (*Streptopelia turtur*) and quail (*Coturnix coturnix*) (Delibes-Mateos 2009). Raptors and carrion eaters such as the golden eagle (*Aquila chrysaetos*), Bearded Vulture-Eagle or bone-breaker vulture (*Gypaetus barbatus*), the Egyptian or white scavenger vulture (*Neophron percnopterus*), and Griffon vulture (*Gyps fulvus*) suffer from the loss of small mammal prey and domestic ungulate carcasses that accompany the loss of open spaces in the Alta Garrotxa to the point where some such as Bonelli's eagle (*Hieraetus fasciatus*) have disappeared altogether (Vila 1999).

#### Domestic livestock history

In the second half of the 1800s up through the middle of the 1900s, the area utilized as pasture was at its maximum in the Alta Garrotxa. There was a high diversity of grazing animals with herders tending to the flocks daily. Livestock were rotated through the

pastures on a regular basis (Lavola 2010). After rapid depopulation of the region in the 1950s, land area in pastures decreased significantly (Cohen et al. 2011).

There are 61 livestock operations in the Alta Garrotxa as of 2010 of which nine utilize organic, traditional methods of agriculture. About half of these are small sheep and goat operations and the other half are large cattle ventures. Cattle require less maintenance because they can be left in the pasture unattended, while sheep and goat require constant vigilance. More than 90% of the pastures utilized are privately owned, with minimal use of public pastures (Lavola 2010).

### Wild Ungulate history

There are six native wild ungulates in the Alta Garrotxa protected open space all of which share a European conservation status of “not threatened/least concern”. The most abundant is the wild boar (*Sus scrofa*) whose range has expanded significantly throughout the Mediterranean region since land abandonment. The Pyrenean chamois goat or isard (*Rupicapra pyrenaica*) is present but rare in the region with evidence that it was part of the faunal assemblage 40,000 years before present. The wild mountain sheep, or mouflon (*Ovis g. musimon*) has a stable population and was introduced into the region as a potential source of food for carrion-eating raptors. The red deer (*Cervus elaphus*) has historically been present in the region and its numbers are expanding. The roe deer (*Capreolus capreolus*) was historically present in the region, experienced extirpation in the 18<sup>th</sup> century, and was reintroduced. The fallow deer (*Dama dama*) has historically been present but is only found rarely in Alta Garrotxa although it is a relatively common species (Pages and Anglada 2006; Pages and Anglada 2008).

### Hunting, and Wolf history

Hunting has long been an important cultural, social and economic activity in the Iberian peninsula (Delibes-Mateos et al. 2009). The Hunting Law of 1970 regulates activities in Catalunya with conditions and management objectives such as the maintenance of species populations, support for biodiversity, control of diseases, and recuperation of species in decline (Serveis Territorials a Girona 2008).

Currently there are 40 areas of private hunting (arees privades de caza – APC) in Alta Garrotxa which include most of the study area. Each APC has a management hunting plan and while large mammals are the predominant game species taken (with the wild boar the most prevalent), statistics compiled by the Department of Environment and Habitat of Catalunya list 29 species that are hunted in Alta Garrotxa (Lavola 2010).

The wolf (*Canis lupus*) was an important predator throughout Catalunya until the early 1900s when poisoning and shootings of the animal by humans led to extirpation. Recent sightings of wolves in Catalunya have been confirmed in 2004 with analysis of scat, and since then up to 13 different individuals have been identified. There are well-established wolf populations in northwest and south central Spain and initially these populations were thought to be the source of the Catalan wolves. Analysis of genetic



material has identified the Catalan wolves to be related to those of the Italian Alps that have migrated through France to reach Catalunya. At this point there has only been one female and no evidence of wolf reproduction. There have also as of yet been no sightings of wolves in Alta Garrotxa (Lampreave et al. 2011).

## Research Context

### Land abandonment and the Mediterranean rural cultural landscape

Researchers advise that to conserve small game species, landscape heterogeneity or patchiness that resulted previously from traditional agricultural practices must be conserved, and pastures in particular (Delibes-Mateo et al. 2009). Traditional agricultural practices included extensive livestock management systems with sheep, cattle, and horses. The foraging of these herbivores are ancient and important causes of landscape heterogeneity in Mediterranean regions (San Miguel-Ayanz et al. 2010). With land abandonment and a decrease in the traditional domestic livestock systems, native ungulate populations are increasing. These wild herbivores could replace domestic ones in maintaining landscape heterogeneity (San Miguel-Ayanz et al. 2010), and contribute to the rewilding of the region that would provide an increase in biodiversity (Soule and Noss 1998; Navarro and Pereira 2012).

The impact of browsing on woody plants depends on the size of the animal and structure of the plants. Browsing the upper shoots of young trees and shrubs produces more damage than browsing lower down as it reduces height, resources sent to roots and new shoots. Heavy browsing may kill plants. Browsers such as the fallow deer, red deer, sheep and goats also strip the bark of woody vegetation (Gill 2006).

In Yellowstone National Park in the western United States, intensive browsing of woody plants by *Cervus canadensis* (elk) significantly diminished *Salix* (willow) and *Populus* (cottonwood and aspen) species (White and Garrott 2005). In the eastern deciduous forests of North America, areas where white-tailed deer (*Odocoileus virginianus*) densities are high (more than 25 deer per square mile), woody and herbaceous plants in the understory are consumed to the point where some species disappear from the forest (Tilgham 1989). White-tailed deer consume woody species preferentially and when deer densities are high, these species do not survive (Arnold and Welch 1996; Pomerantz and Welch 1996).

Zamora et al. (2001) investigated the impact of ungulate browsing on sapling growth in three native forests in southeastern Spain. Ungulates consumed 30% of apical shoots and 85% of the saplings were browsed more than once thereby retarding sapling growth by twelve years. They concluded that browsing by ungulates is a major factor hindering regeneration of Scots pine (*Pinus sylvestris*) in southeastern Spain (Zamora et al. 2001).

Ungulates that use woodland habitats vary in their consumption of grass versus forb-fruit versus trees and shrubs. The following table is from Van Dyne et al. 1980 that

presents selected information about some of the wild and domestic ungulates found in Alta Garrotxa.

Table 1. Composition (%) of the diet of large herbivores that use woodland habitats

Species	Grass	Forb + Fruit	Tree/shrub
Capreolus capreolus Roe Deer	7	15	78
Dama dama Fallow Deer	29	12	59
Cervus elaphus Red Deer	40	21	39
Sus scrofa Wild Boar	36	62	2
Goat	29	12	59
Sheep	50	30	20

Source: Van Dyne et al. 1980

Landscapes that support diverse populations of ungulate assemblages are enhanced by high soil nutrients in combination with intermediate precipitation (Olf, Ritchie and Prins 2002), and high spatial heterogeneity of ecosystems (du Toit and Cumming 1999). Browsers respond to precipitation, and species richness peaks at about 600mm/year (Prins and Fritz 2008). Average annual rainfall in Alta Garrotxa is about 700mm/year, but with great spatial variation across the site (Vila 1999).

In wild assemblages, if the consumers of a trophic level are generalists, then there is little increase in biomass or productivity with increased diversity. If consumers are specialists, complementary use of resources would increase diversity and production of biomass (Prins and Fritz 2008).

Of the native ungulates found in Alta Garrotxa, the wild boar is most numerous and found throughout the study area (Pages and Anglada 2007). The wild boar is an omnivore the diet of which is secured predominantly through foraging for forbs and fruit. The potential impact of wild boar in maintaining open woodlands is through consumption of acorns and other woody plant fruits which results in reduced seedling establishment (Gill 2006).

The mouflon is the second most sighted wild ungulate in the study area (Pages and Anglada 2007). Thought to be one of two wild ancestors of modern domestic sheep breeds, it is more of a grazer than a browser. The mouflon prefers steep, mountainous habitat near the tree line. During the winter season they move down slope into lower elevations (MacDonald and Barret 1993). The mouflon population has been encouraged in Alta Garrotxa because the carcasses are thought to provide food for the threatened and endangered raptors (Pages and Anglada 2006).

The red deer is the largest deer found throughout Europe and expanding into the study area (Whitehead 1972). Red deer are large, wild ungulates that reside in open habitats although recently they have taken refuge in deciduous forests. In a survey of red and roe deer populations in northwest Spain, Barja and Rosellini (2008) observed red deer utilizing closed (45.2%) and open (54.8%) habitats similarly, while they observed roe deer more often in closed (69.7%) than open (30.3%) habitat types.

Red deer in the Mediterranean landscape show a preference to browse on *Arbutus unedo*, *Phillyrea angustifolia*, *Quercus spp.*, *Quercus ilex*, and *Rubus fruticosus*. Less preference is shown to browse *Cistus ladanifer*, *Daphne gnidium*, *Erica arborea*, *Lanadula stoechas*, and *Rosmarinus officinalis* (Acevedo et al. 2008).

The roe deer is intermediate in size, and a forest species but it can occupy different habitat types from forest to human-dominated plains (Barja and Rosellini 2008). Jepsen and Topping (2004) note that roe deer exhibits behavioral flexibility among ungulates in that it has rapidly expanded its range from the original forest-mosaic habitat into agricultural plains. This species is a woody browser and has great potential to contribute to the management of woody species in Alta Garrotxa through browsing.

In Asturias, Spain, the roe deer is known to eat a wide range of plants that include berries, heath, bushes (dogwood, strawberry tree, birch, and conifers), broad-leaf trees (chestnut, oak, hazelnut, maple, laurel), fruits, ivy, ferns, willows, fungi and mushrooms. With a small stomach, the roe deer eats frequently and can eat plants that contain phenols and tannins which are toxic to most (Bernaldo 2007).

Native to southern Europe, the fallow deer had been hunted to extirpation in many places in Europe. A small deer of the forest, it is more of a woody plant browser than a grazer, and if numbers increase, could serve to maintain open spaces in Alta Garrotxa (Whitehead 1972).

About 3000 Pyrenean chamois goats (*Rupicapra pyrenaica*) died in northeast Spain from 2005-2007 due to a viral infection (Marco et al. 2009). Recovery of this population has been slow but continues. As a woody plant browser, larger chamois goat populations would help to maintain open woodlands (Prins and Fritz 2008).

### Predator-prey relationships

To achieve equilibrium in the native ungulate population once population densities reach management goals, a predator-prey system must be promoted. Humans serve in this capacity through hunting, but often hunting focuses on trophy animals and does not function to improve the health of the prey population. For Alta Garrotxa, wolves would be the best large mammal predator, and research indicates that wolves prey on the more abundant ungulate species in Alta Garrotxa; wild boar, red deer, and roe deer (Jedrzejewski et al. 2002; Gazzola et al. 2005; Barja and Rosellini 2008).

Without wolf predation, there is the possibility that native ungulate populations could irrupt and then with overpopulation, experience a significant dieback that would result in

wildly fluctuating landscape processes (Jedrzejewski et al. 2002). There is understandably resistance from domestic livestock ranchers to the reestablishment of wolves in the Pyrenees, but research shows that wolves prefer wild ungulates to domestic, and the cervids in particular. In a study in the western Alps of Italy, wild ungulates represented 87.2% of wolf prey even when domestic livestock were readily available. Cervids were the preferred prey at 74.2% as the dominant winter (84.2%) and summer (54.3%) food (Gazzola et al. 2005).

Red deer is the preferred food of the wolf in the western Alps of Italy (Gazzola et al. 2005), and Bialowieza Primeval Forest in Poland (Jedrzejewski et al. 2002). There is an indication that wolf predation reduces annual population growth rates, but the population of red deer is still increasing in the Bialowieza Primeval Forest in Poland (Jedrzejewski et al. 2002). Hunting may complement wolf predation to achieve red deer population equilibrium.

In Yellowstone National Park in the western U.S., 31 wolves were reintroduced in 1994-95. The elk (*Cervus canadensis*) is their preferred prey at 92% of all captures, with an occasional bison (*Bison bison*), moose (*Alces alces*), and mule deer (*Odocoileus hemionus*) included in their diets. The bighorn sheep (*Ovis canadensis*) and pronghorn antelope (*Antilocapra americana*) are not affected by the wolves (White and Garrott 2005). The elk population has been reduced by 50% due to wolf predation of senescent individuals and calves, and also from continued human hunting. Because of high numbers of elk browsing in the park, loss of woody habitat became a concern and wolf reintroduction was part of elk population management objectives (White and Garrott 2005).

Wild boar is a food of wolves, but they feed mostly on piglets in spring and summer (Jedrzejewski et al. 2002; Barja and Rosellini 2008). In the Montes do Invernadeiro Natural Park in northwestern Spain, roe deer (62% frequency in scat) is the preferred food of the Iberian wolves followed by red deer (12.6% frequency) and wild boar (10.0%) (Barja and Rosellini 2008).

Researchers who investigated the impact of predation risk by wolves versus human hunting and forest exploitation in the Bialowieza Forest, Poland found that ungulates did not avoid areas selected by wolves. Human activities (hunting and forest exploitation) adversely affected ungulate distribution density more than predation risk by wolves (Theuerkauf and Rouys 2008).

### Wolf history and ecology

Successful wolf pack establishment is dependent on availability of prey (Schmidt and Mech 1997), but more importantly, road density and habitat area. Wolves are sensitive to human presence as exposure to humans is the primary cause of wolf mortality. Wydeven et al. (2001) investigated the relationship between wolf mortality rates and road density and found that death of wolves by shooting or vehicle collisions occurred at road densities of 0.84 to 1.14 km/km<sup>2</sup>. Mech et al. (1988) corroborated that there is a

0.58 km/km<sup>2</sup> threshold level or road density above which wolves do not occur in North America.

Related to prey availability, the minimum habitat requirement for the Eastern Timber Wolf in North America is at least 129 km<sup>2</sup> per 1 wolf (Harrison and Chapin 1998). The shape of the habitat area is also relevant, and a more circular habitat patch shape is preferred by wolves. In landscape ecology, the landscape fractal dimension (D) was significantly lower in areas where wolf packs are found according to Mladenoff et al. (1995). This may be an indication of less habitat fragmentation and minimal human presence.

In Yellowstone National Park in the western part of the United States, wolf restoration in 1994-95 was predicted to follow elk populations and range between 50-130 individuals. As of 2004, wolves have reproduced at the biological maximum with 159 wolves in 14 packs residing in the Park with a density of greater than 50 wolves per 1000 km squared. The elk population has been reduced more (50%) than expected (5-30%) although human harvest of elk has not decreased. The antler-less (hind) permits have been reduced in 2000-2004 to protect females of reproductive age (White and Garrott 2005).

A study by Blanco and Cortes (2007) in northwest central Spain found wolf densities of 1.63 packs per 1000 km squared (a pack is 3 or more wolves) in the area north of the Duero River, and 0.77 south of the river. Road densities are 0.40 km per km squared for paved roads, and 1.53 km per km squared for permanent roads. The average home range of the wolves is 15 km, and the average area is 182 km squared (Blanco and Cortes 2007).

In the Bialowieza Primeval Forest in Poland, the mean size of the wolf hunting group was 4.4 individuals, and wolves killed 0.513 +/- 0.04 prey/pack per day. Larger wolf packs killed larger animals. The typical wolf home range was 100-300 km squared, and there were 2-2.6 individual wolves per 100 km squared (Jedrzejewski et al. 2002).

### Native Ungulate Densities

In one study, researchers noted that a survey of deer populations under predation by wolves were high at 2.6 individuals per square kilometer for red and 5 for roe deer (Barja and Rosellini 2008). In the Bialowieza Primeval Forest in Poland, wild ungulate densities were 10 individuals per km squared and this included 5 species: red and roe deer, wild boar, European bison (*Bison bonasus*) and moose (*Alces alces*) (Jedrzejewski et al. 2002).

Studies on red deer density conclude that in a closed canopy forest, a density of 0.5-3 deer per 100 ha maintains the forest woody species composition, whereas in woodlands, woody shrub regeneration occurs with densities as high as 30 deer per 100 hectares (Vera et al. 2006). Researchers in southern Spain studied red deer density at a number of hunting estates and found low to medium densities of 0.5-20 individuals per 100 ha, as well as high densities of 21-65 individuals per 100 ha (Acevedo et al. 2008).

Roe deer have recolonized or been reintroduced into Catalunya since the 1970s such that there is a relatively continuous distribution in the Pre-Pyrenean and Pyrenean regions. Once densities reach 5-6 individuals per 100 ha, hunting is allowed for up to 5% of the population. In l'Alt Pallars-Aran region, roe deer densities oscillate between 5-8 per 100 ha, and in some sectors, reach 20 (Marco 2007).

In the Parc Natural de la Zona Volcanica de la Garrotxa, 29 female and 20 male roe deer were released between 1995-1998. Densities ten years later average 2-2.5 individuals per 100 ha with some areas around 7. Problems reported due to roe deer include animal-vehicle collisions, and plantation and legume plant damage. Damage prevention efforts are underway. No damage to the forest has been noted (Rosell et al. 2007).

### Methods and Data

In order to evaluate the potential role of wild ungulates as a process in maintaining an open woodlands landscape, we reviewed the literature on ungulate and wolf ecology in Mediterranean regions, Europe, and North America, and gathered recent and current data on ungulate and wolf populations in Alta Garrotxa. The research methodology was a two-pronged approach and involved a search for historical data for each of the species that forms a part of the ungulate community of Alta Garrotxa. This included a bibliographic search for studies and surveys about the historical presence of ungulates in the study area. It also included information from relevant governmental and local groups such as the Department of the Environment and Housing, Territorial Services of Girona, and Departmental Federation of Hunters of the Oriental (Eastern) Pyrenees about catch statistics, reintroductions, and data from Private Hunting Areas (APCs). Other local sources of historical data were surveys from hunters, property owners, ranchers, and naturalists.

The second research methodology involved a diagnostic of the current situation using recent ungulate population sightings data from private hunting groups (APCs). A spatial analysis of the abundance and distribution of each of the ungulate populations was possible because of the private hunting club data for their specific area for all species. With the use of Geographic Information Systems (GIS), spatial display of existing ungulate populations and estimated densities show where populations currently exist.

For this research, we developed and mapped the frequency index according to the abundancy classes after Pages and Anglada (2008). The abundancy classes allow for the visualization of the demographic tendencies of different ungulate populations over the study area. The frequency index is the percent of the hunts where a particular ungulate species was bagged compared to all the hunts for that private hunting area (APC).

We then constructed an abundance gradient with three classes to display the current distribution and abundance of ungulate species in Alta Garrotxa. The three classes are:

Low: Frecuency is < 33.3%

Medium: Frequency is 33.3% ≤ 66.6%

High: Frequency is > 66.6%

To display the observations across the map, the study area was divided into a grid with cells of 263.9 ha which is the average size of the private hunting areas and hence hunts in Alta Garrotxa. The grid was overlain onto the map with the private hunting areas and the abundance class data point for a species was displayed in the grid square where more than 50% of the private hunting area was found.

To calculate recent ungulate densities, data for both sightings and hunting kills from Alta Garrotxa for each time period were analyzed. For a particular ungulate species, the total number of animals sighted was divided by the total area in square kilometers where sightings for all species were reported. The same methodology was used for hunting kills. A comparison of recent ungulate densities to data from other regions gives an indication of the level of browse pressure that the Alta Garrotxa currently experiences, and offers guidelines for potential population density targets to achieve management goals.

Evaluation of research findings on wolf ecology in Europe and North America provides a context for considering wolf reintroduction or natural expansion into Alta Garrotxa. Previous studies offer data about the interaction between wolves and human hunting as well as domestic livestock and wild ungulates as food resources. The private hunting areas' clubs provided much of the data for ungulate populations in Alta Garrotxa that is collected and published by the Consortium of the Alta Garrotxa (Consorti de l'Alta Garrotxa) in collaboration with the Generalitat de Catalunya's Department of Environment and Habitat (Departament de Medi Ambient i Habitatge).

## Results and Discussion

Current wild ungulate species in the Alta Garrotxa have great potential to significantly browse woody species to maintain landscape heterogeneity with the exception of the mouflon which is predominantly an herbaceous plant grazer. The roe and red deer are the two ungulates with the greatest potential to contribute to woody plant browsing.

The climate and biogeography of the region provide for excellent habitat and high primary production for the wild ungulate assemblage of Alta Garrotxa (Olf, Ritchie and Prins 2002; du Toit and Cumming 1999). The preferred food of these ungulates is found in Alta Garrotxa (Acevedo et al. 2008; Bernaldo 2007). In particular, for the red deer there are a number of *Quercus* species in the Alta Garrotxa along with *Rubus* and *Erica arborea* (Vila 1999).

The roe deer has a wider palate and many of the species the roe deer finds palatable are found in the Alta Garrotxa. These include the *Quercus* (oak), *Corylus* (hazelnut), *Castanea* (chestnut), *Acer* (maple), and *Daphne* (laurel) broad-leaf trees (Vila 1999).

The distribution maps of approximate ungulate distribution in Alta Garrotxa are created from APC sightings and takings data from 2005-06 (Pages and Anglada 2006), and each of the colored subareas are the 40 APC (private areas of hunting) that are found within the boundary of the Alta Garrotxa. Figure 5 shows the approximate distribution of *Capreolus capreolus*, the roe deer. Figure 6 is for *Cervus elaphus*, the red deer, Figure 7 is for *Ovis g. musimon*, the wild mountain sheep or mouflon, Figure 8 is for *Dama dama*, the fallow deer, and Figure 9 is the approximate distribution map for *Rupicapra pyrenaica*, the Pyrenean chamois goat or isard. The results show that *Sus scrofa*, the wild boar, is found in high numbers throughout Alta Garrotxa as 39 APC report sightings and harvests (Pages and Anglada 2008).

Figure 5. Distribution of *Capreolus capreolus*, the roe deer, by APC in 2005-06, Alta Garrotxa

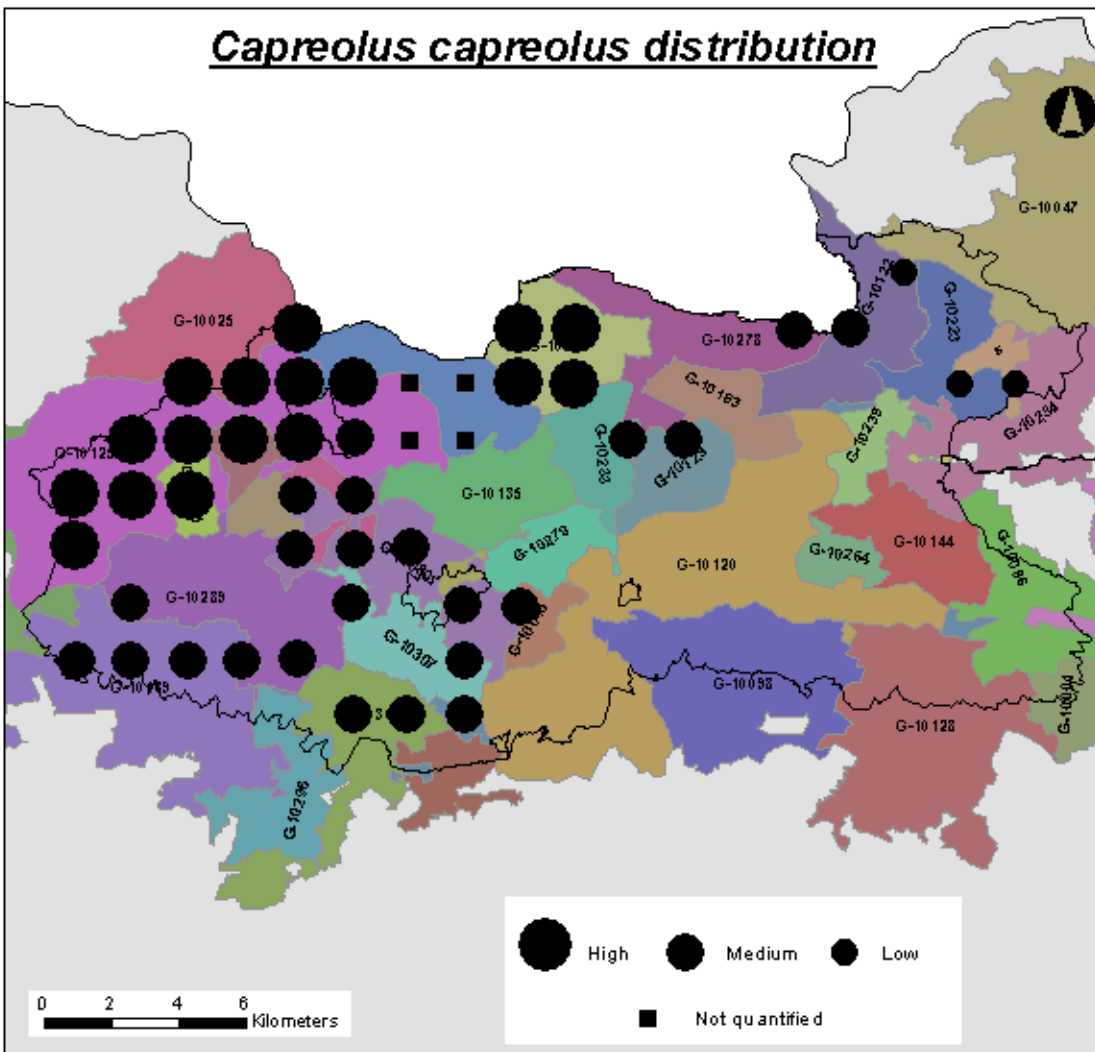


Figure 6. Distribution of *Cervus elaphus*, the red deer, by APC in 2005-06, Alta Garrotxa



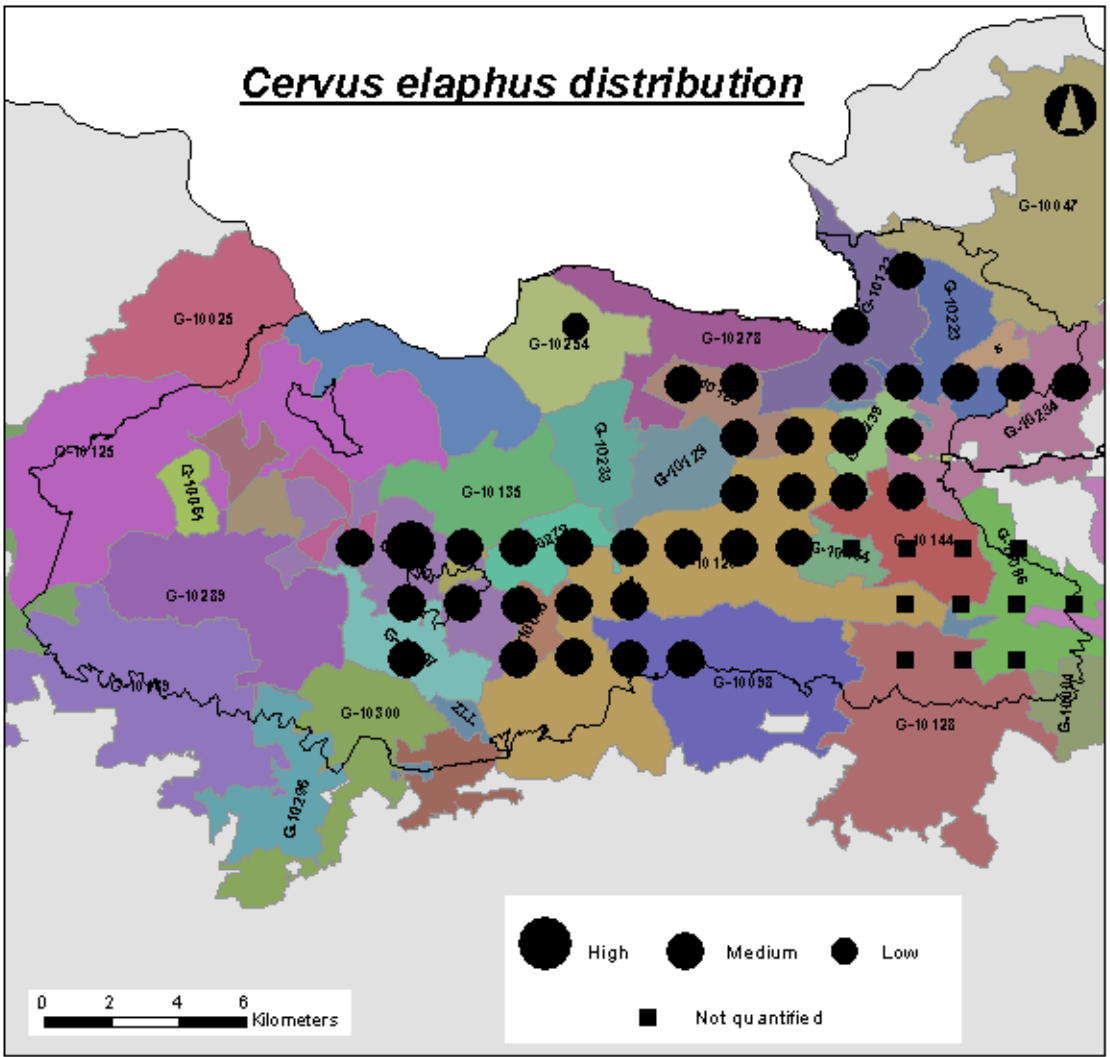


Figure 7. Distribution of *Ovis g. musimon*, the wild mountain sheep or mouflon, by APC in 2005-06, Alta Garrotxa

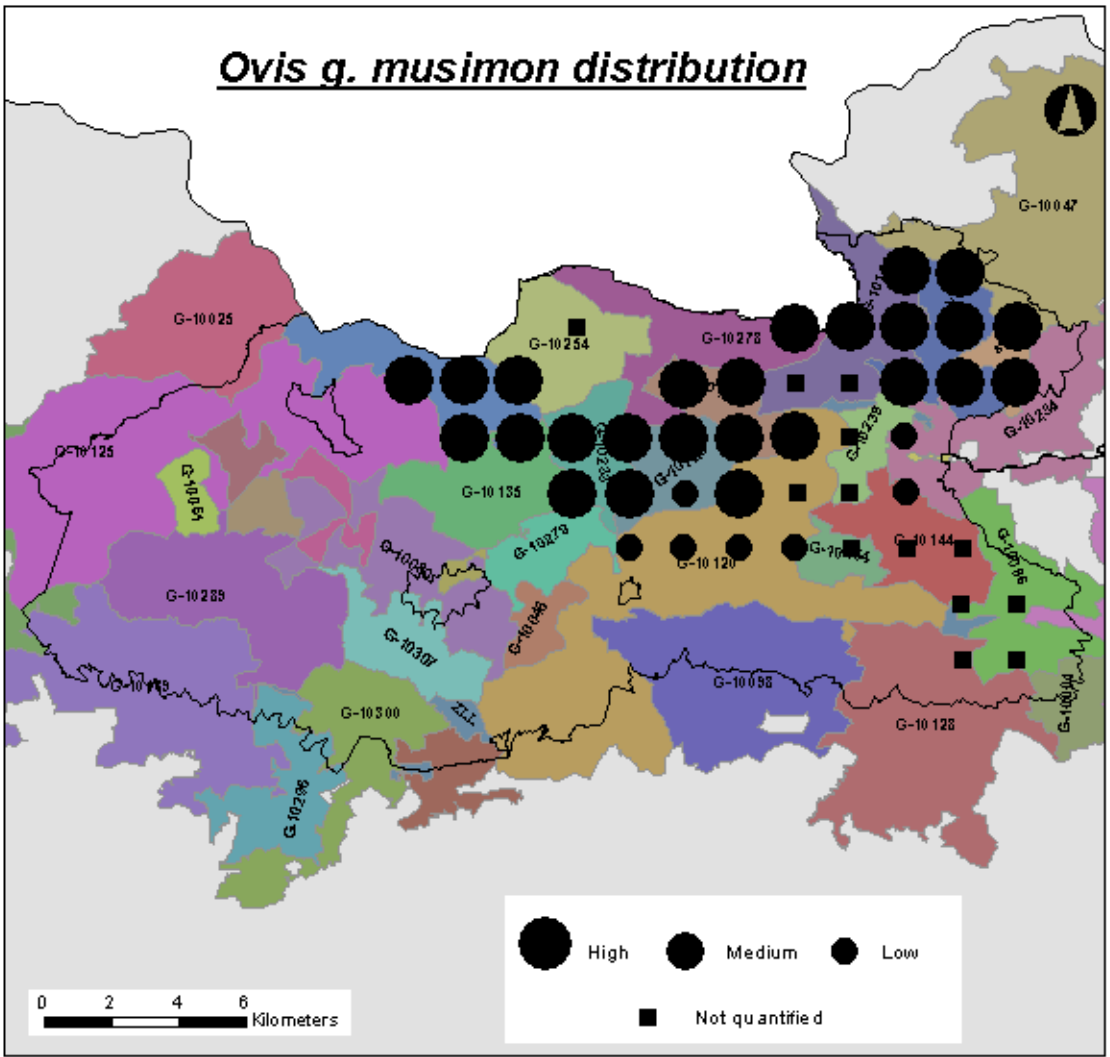


Figure 8. Distribution of *Dama dama*, the fallow deer, by APC in 2005-06, Alta Garrotxa

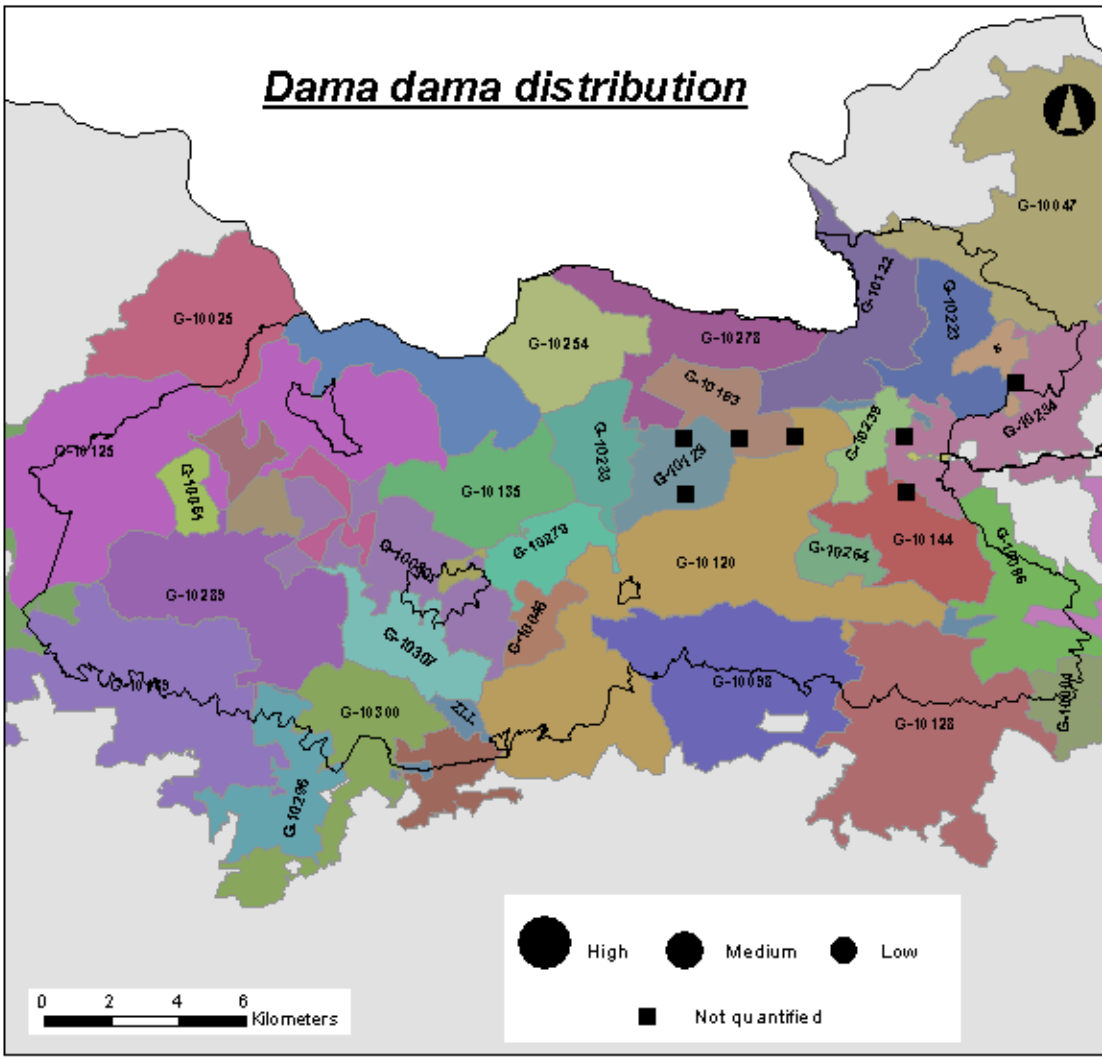


Figure 9. Distribution of *Rupicapra pyrenaica*, the Pyrenean chamois goat or isard, by APC in 2005-06, Alta Garrotxa



2006-07 (2)	0	0.05	2.43	2.16	0.03	0
2006-07 (3)	0.19	0.24	3.42	1.12	1.58	0
2004-09 av. (4)	0.04	0.09	5.85	0.51	0.06	0
Park Zona Volcanica (5)	2-7					
Spain, low- medium (5, 6)	2.6	5 0.5-20				
Spain, high (7)	5-6	21-65				
Europe low High (8)		0.3-3 30				

- (1) Pages y Anglada 2006
- (2) Pages y Anglada 2007
- (3) Serveis Territorial Girona 2008
- (4) Lavola 2010
- (5) Rosell et al. 2007
- (6) Acevedo et al. 2008
- (7) Barja and Rosellini 2008m
- (8) Vera et al. 2006

With the land abandonment and landscape changes from more open pastures and woodlands to closed canopy forest (Vila 1999, Cohen et al. 2011), mammal populations are shifting from smaller to larger species. The larger species include the native wild ungulates a number of which are woody plant browsers. The data show that the native populations are established and expanding in Alta Garrotxa but the population densities have not yet reached a level where browsing will have a significant impact on woody plants.

Given the data from other studies in Spain and Europe, the roe deer populations should be managed for densities around 5-6 individuals per km<sup>2</sup>, and around 20 for the red deer. Once these levels have been reached, a woody vegetation survey should be conducted to evaluate the impact of these densities for maintenance of landscape heterogeneity.

The wolf has returned to Catalunya, and with increasing numbers of ungulates available in Alta Garrotxa, wolves may return to the area on their own. There are numerous benefits to the establishment of a top-level predator in Alta Garrotxa. Studies have shown that wolves prefer native ungulates over domestic and so as the native ungulate populations expand, wolves will provide a population control pressure that will also improve the health of the herds by culling the old and weak individuals (Jedrzejewski et. al 2002; White and Garrott 2005).

When wolves kill an animal, the carcass is left in the area for other animals to utilize. In a study of wolf predation in Banff National Park, Hebblewhite (2007) noted that carcasses left by wolves provided carrion and carcasses to a wide range of animals including golden eagles (*Aquila chrysaetos*). With wolves in the Alta Garrotxa, carcasses will once again be available to the raptors and carrion eaters to conserve and promote biodiversity.

Table 3 synthesizes research findings on wolf habitat area requirements in North America and Europe. The Alta Garrotxa is part of a larger pre-Pyrenean landscape but the area of the Alta Garrotxa alone at 328.65 square kilometers and approximately 18 km across is large enough for a pack of wolves.

Table 3. Wolf Habitat Area Requirements

Location	Road Density	Wolf density individuals	Wolf density packs	Area	Home Range
North America (1)	<0.58 km/km <sup>2</sup>	1		129 km <sup>2</sup>	
Yellowstone Park (2)		50 1		1000km <sup>2</sup> 20km <sup>2</sup>	
Central Spain North South (3)	0.40 km/km <sup>2</sup> paved roads 1.53 km/km <sup>2</sup> overall av.	1	1.63 0.77 (3+/pack)	182km <sup>2</sup> 1000km <sup>2</sup> 1000km <sup>2</sup>	15km
Poland (4)		2-2.6 1		100km <sup>2</sup> 50km <sup>2</sup>	10-17km

(1)Mech et al. 1988; Harrison and Chapin 1998

(2)White and Garrott 2005

(3)Blanco and Cortes 2007

(4)Jedrzejewski et. al 2002

Hunting of wild ungulates in the Alta Garrotxa is a potential management tool in combination with a top-level predator, the wolf. Calculated from data in Table 4, the average total number of wild ungulates harvested per year from 2004-2009 is 1623.6.

Table 4. Number of Ungulates Harvested by Hunting in Alta Garrotxa 2004-2009

Species	2004-05 Harvests	2005-06 Harvests	2006-07 Harvests	2007-08 Harvests	2008-09 Harvests	Average Harvests	Number of APC out of 40
Roe deer	3	8	14	13	30	13.6	14
Red deer	30	23	28	28	32	28.2	14

Fallow deer	33	22	9	17	16	19.4	8
Mouflon	218	205	180	142	89	166.8	20
Wild Boar	1538	1431	1586	1281	1142	1395.6	39

Source: Lavola 2010

According to the research from the Bialowieza Primeval Forest in Poland, wolves killed 0.513 +- 0.04 prey/pack per day (Jedrzejewski et al. 2002), which would translate to approximately 180 animals per year in the Alta Garrotxa depending on pack and ungulate size.

## Conclusion

The results of the research indicate that native wild ungulates in the Alta Garrotxa have great potential to consume woody plant species sufficiently to maintain the historical, cultural, open woodlands of the Mediterranean region. To replace the domestic ungulates in the landscape, wildlife management efforts should increase population densities of the native ungulates significantly to about 5 per square km for the roe deer, and 20 for the red deer. Management efforts should also work to increase populations of fallow deer and the Pyrenean chamois goat. A top-level predator, the wolf, and hunting by humans would simultaneously serve to maintain the health and population numbers of the native ungulates.

Future research questions include the relationship between ungulate densities and woody browse preferences. When there is plenty to eat and ungulate densities are low, do the animals demonstrate preference for one species over another? When ungulate population densities are high, do the preferences shift or disappear? Is there complementary browsing between specialists or overall browsing amongst generalists? Finally, do the native wild ungulates successfully replace the domestic ungulates as a landscape process that maintains the open spaces and biodiversity of the Alta Garrotxa?

The larger question relates to promoting landscape processes that are sustainable over time, and that maintain or increase biodiversity. This will require establishment of a top level predator such as the wolf because ungulate population irruption could lead to excessive browsing of woody species and forest degradation (Arnold and Welch 1996; Pomerantz and Welch 1996; White and Garrott 2005). Another research effort would focus on an evaluation of the suitability of Alta Garrotxa as wolf habitat and the potential for successful wolf recolonization or reintroduction.

As the financial crisis deepens in this region and agricultural support for domestic livestock operations wanes, promotion of native ungulates and a top level predator could present a least-cost option for protected lands management. Considering the relationship between nature and human society, research should also address whether

rewilding of the landscapes of Alta Garrotxa will promote increased biodiversity and stability.

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