UNIVERSITÀ DEGLI STUDI DEL MOLISE

Department of Agricultural, Environmental and Food Sciences

PhD Course in:
AGRICULTURE TECHNOLOGIES AND BIOTECHNOLOGIES
(Curriculum: Animal Welfare, Biotechnology and Quality of Animal Production)

CYCLE (XXXIV)

Related Disciplinary Scientific Sector: AGR/18 (Animal nutrition and Feeding)

PhD Thesis

Management of locally abundant wild mammals in a landscape context thorough Geographic Information System (GIS): experimental approaches to wild boars

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Academic Year 2020/2021

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ABSTRACT

Wildlife, and in particular wild ungulates, have undergone a strong demographic increase throughout Europe, especially in the last thirty years. Today the development of wild ungulates represents one of the most relevant changes of the Italian wildlife in the last decades. The occurrence of damages by wild boars raised dramatically in the last decades and amounts to hundreds of thousands of Euros per year in several European countries. This species is considered invasive and damaging to agriculture and environment. The wild boar has been listed in the 100 “World's Worst Invaders” by the IUCN's group of invasive species specialists. In the Molise Region the presence of these ungulates is particularly high. This is mainly due to: the abandonment of the countryside and in particular of Apennines areas; the strong reforestation habitat; the climate change and the considerable food availability; the increase of areas off-limits to hunting activity linked to the rise of protected areas (Parks and Protected Areas, Oases, Restocking and Capture wildlife Areas, Dog Training Areas, etc.). The considerable diffusion of these ungulates caused an increase of the human-wildlife conflict in anthropized areas. In contrast to many other ungulates, the wild boar is an omnivore and inhabits a vast range of habitats. This situation often determines serious conflicts with humans. The wild boar (*Sus scrofa*) greatly expanded their distribution areas because of the progressive adaptation to the most varied ecological and environmental conditions linked in most part to modified biological factors. In thirty years, the home-range has quintupled, involving different geographical areas. Wild boars are now diffused from lowlands to hilly and mountainous areas; the presence of wild boars have been observed also in the periphery of urban areas. The strong impact that the wild boar has on some activities of economic interest contributes to sharpen the contrasts between social categories (hunters, farmers, foresters, public entities) having divergent interests. The conflict of interests linked to the presence of the wild boar on the territory, together with some difficulties of technical nature (for example related to the quantitative estimate of the population), makes the management of this species particularly problematic. In fact, the management policies are inadequate as the lack of technical organization. The knowledge of distribution, abundance and population dynamics is essential for their correct management, especially for the Wild boar (*Sus scrofa*) considering its impact on the natural and agricultural ecosystem. Today, the serious lack of money invested by institutions to estimate the wild boars population and its biological characteristics (e.g. potential rates of population growth), together with the limited knowledge in this field determine considerable difficulties to face and solve these problems. The first step in the management policies is to determine the wild boars populations and the possible changes coming out from the territories, appreciating their incidence on the trophic scale in a given environment. The estimation of the density of wildlife is fundamental to improve the management and conservation of this resource. The knowledge of the number of animals is fundamental to plan correct systems to prevent the risk of damages to the agricultural and forest environment. To determine if the damage is tolerable or not in a territory, the need for intervention must be assessed. Indeed, the same presence of wild boar in protected areas has positive aspects because they play an important role in the food chain and in the trophic cascade (large carnivores), provided that it does not exceed certain thresholds and become an ecological problem. The optimal density depends on the socio-environmental characteristics of the territory, the damage recorded and the conservationist specific needs. It is important to underline that the management of damages is not limited only to the quantitative aspects, but also to the different ways of perception of it. From a practical point of view, this problem has to be discussed and shared by all the social components involved in the management of the

species, such as the comparison between the average "value" in terms of money paid for damage and prevention. So far, the sustainable planning and the objective-density parameters should not be considered as immutable values, because they refer to the principle of adaptive management and may vary over time. This evidence indicates that wild boar numbers have resulted in an increase in conflicts between humans and wild ungulates. These clashes arise for different reasons, including damage to agricultural crops and property, the risk of disease transmission to humans, livestock or other domestic animals, road collisions with vehicles, and damage to forests and their regeneration. In this context estimating population densities is an essential part of successful wildlife management and the responsible management of their populations; the limitations of their negative impacts will become a major challenge. While there is an overwhelming number of scientific articles describing and discussing problems related to the wild boar population (and its growth), only limited information is present on possible solutions. This research initially focused on the study of the species, searching from the bibliography for a series of information regarding the biology, the ethology and impact that the species causes on the different contexts in which it is found today which varies from cultivated fields, pastures used for the traditional zootechnics, protected areas such as parks, oases, areas forbidden to hunting up to anthropized areas and urban contexts. Subsequently, it was evaluated the potential of the Geographic Information System (GIs) software and its application in wildlife management of large mammals, especially on wild boar species. Finally, the application of this knowledge was planned for the creation of models and maps useful for the political and technical decision-maker working in wildlife management. This is to improve and make more effective the actions on the territory for the adaptive management of this species, especially in a landscape that presents itself with a scarcity of economic and human resources, with great difficulty in repeating updated data. The results of these studies are presented in the form of submitted and published manuscripts (indexed journals Scopus/WOS):

- **Part I:** ***Assessing the risk of damages by wild boars (Sus scrofa) in Italian landscapes and relation to the incidence of road accidents: the case of Molise Region***

It was studied the spatial analysis of the Molise area in order to identify areas for the control of the species and consequent containment measures based on the law 157/92 for the protection of agricultural and anthropized areas. The research has therefore evolved and led to the creation of a map of potential impact of wild boars in the Molise Region, a map that has never been drawn up before for these territories. The map was elaborated through the use of GIS programs (specifically OSGEO QGIS 3.10.4); it is based on a spatial DBMS (Data Base Management System) that is able to manage the positions of the elements on the territory because they are associated with geographic information as well as textual and numerical information. and validated through the verification and mapping of road accidents in the Molise Region.

- **Part II:** ***Wild Boar in urban and peri-urban areas: corridor elements of the landscape in an urban area of Southern Italy***

In this study, environmental variables related to the species were analysed in order to identify elements of the ecological network linked to the wild boar in the city of Campobasso. A spatial model of the ecological network was created using various information layers. This model was verified by searching for sightings of wild boars made by citizens and reported to local newspapers and social networks through photos and videos and mapped on the territory. The mapping was used to verify near the sightings what were the relevant correlations of the environmental variables and the ecological structures that drive the wild boars into the city.

- **Part III:** ***Estimation of the wild boar population in Southern Italian Apennines by Pellet Count Group technic. Preliminary results***

This paper proposes an estimate of the wild boar population in a study area, located in the south / south-eastern part of the Italian Apennines. The census technique was planned through field inspections and cartographic elaborations using GiS software and the Pellet Count Group technic. The data of the Pellet Group discovery were marked on special field cards. A database was created by estimating the population by number of reliefs and habitats.

- **Part IV:** ***Behaviour to changing conditions of wildlife species in urban areas during lockdown: a review***

Other elements of study concerned the behaviour to changing conditions of wildlife species in urban areas during COVID 19 lockdown. This paper will highlight various adaptations and changes in behavior developed by wild animals in urban areas during the early pandemic period. They concerned the effects on wildlife and ecosystems that are related to human activities, possible interactions between humans and wildlife, and the perspectives on wildlife and ecosystem management going forward.

RIASSUNTO

La fauna selvatica, ed in particolare gli ungulati selvatici, hanno subito un forte incremento demografico in tutta Europa negli ultimi trent'anni. Il verificarsi di danni da parte degli ungulati selvatici in particolare, dei cinghiali è aumentato drammaticamente negli ultimi decenni e ammonta a centinaia di migliaia di euro all'anno in diversi paesi europei. Questa specie è considerata fortemente invasiva e dannosa per l'agricoltura e l'ambiente, infatti è stato inserito nella lista dei 100 “peggiori specie invasive del mondo” dai gruppi di specialisti della IUCN. In Molise la presenza di questi ungulati è particolarmente elevata. Ciò è dovuto principalmente: all'abbandono delle campagne; l’avanzata del bosco; il cambiamento climatico, la notevole disponibilità di cibo; l'aumento delle aree interdette all'attività venatoria legate all'innalzamento delle aree protette (Parchi e Aree Protette, Oasi, Aree Faunistiche di Ripopolamento e Cattura, Aree di Addestramento Cani, ecc.). La notevole diffusione di questi ungulati ha determinato un aumento dei conflitti uomo-fauna selvatica. Il primo passo nelle politiche di gestione adattativa di una specie è lo studio dell’ambiente e le sue variabili, oltre alla determinazione delle stime di popolazione. Le densità ottimale dipende dalle caratteristiche socio-ambientali del territorio, dal danno registrato e dalle specifiche esigenze gestionali. È importante sottolineare che la gestione del danno non si limita solo agli aspetti quantitativi, ma anche alle diverse modalità di percezione dello stesso e allo studio delle caratteristiche qualitative ambientali in ciascun contesto. Questa ricerca si è inizialmente concentrata sullo studio della specie, ricercando in bibliografia una serie d’informazioni riguardanti la biologia, l'etologia e l'impatto che la specie provoca sui diversi contesti in cui si trova oggi, che varia dai campi coltivati, ai pascoli utilizzati per la zootecnia tradizionale, aree protette quali parchi, oasi, aree interdette alla caccia fino ad aree antropizzate e contesti urbani. Successivamente sono state valutate le potenzialità dei software GIS (Sistemi Informativo Geografici) e la loro applicazione nella gestione faunistica dei grandi mammiferi, in particolare sulle specie cinghiale. Infine, l'applicazione di queste conoscenze è stata pianificata per la creazione di modelli e mappe utili ai decisori politici e tecnici che operano nella gestione della fauna selvatica. Questo per migliorare e rendere più efficaci le azioni sul territorio per la gestione adattativa di questa specie, soprattutto in contesti che si presentano con una scarsità di risorse economiche e umane, con grande difficoltà a ripetere dati aggiornati. I risultati di questi studi sono presentati sotto forma di manoscritti inviati e pubblicati (riviste indicizzate Scopus/WOS):

• *Parte I: Valutazione del rischio di danni da cinghiale (Sus scrofa) nei paesaggi italiani e relazione con l'incidenza degli incidenti stradali: il caso della Regione Molise*

E' stata studiata l'analisi spaziale dell'area molisana al fine di individuare aree di controllo della specie in base alla Legge Nazionale 157/92 per la tutela delle aree agricole e antropizzate.

• *Parte II: Il cinghiale nelle aree urbane e periurbane: elementi di corridoio del paesaggio in un'area urbana del Sud Italia*

In questo studio sono state analizzate le variabili ambientali relative alla specie al fine di identificare gli elementi della rete ecologica legata al cinghiale nella città di Campobasso.

• *Parte III: Stima della popolazione di cinghiali nell'Appennino meridionale italiano mediante tecnica Pellet Count Group. Risultati preliminari*
Questo lavoro propone una stima della popolazione di cinghiale in un'area di studio situata a sud dell'Appennino Italiano, tramite il metodo del Pellet Count Groups.
• *Parte IV: Comportamento al cambiamento delle condizioni delle specie selvatiche nelle aree urbane durante il blocco: una rassegna*
Altri elementi di studio hanno riguardato il comportamento di alcune specie in aree urbane durante il lockdown dovuto al COVID 19.

General objectives of the thesis

The occurrence of damages by wild boars raised dramatically in the last decades and amounts to hundreds of thousands of Euros per year in several European countries. The knowledge of distribution, abundance and population dynamics is essential for their correct management, especially for the Wild boar (Sus scrofa) considering its impact on the natural and agricultural ecosystem. The thesis is focused on the evaluation of the potential of the Geographic Information System (GIs) software and its application in wildlife management referred to wild boar species and to some of the most important cases of accidents such as the incidence of road accidents, the identification of corridor elements of the landscape in urban areas and the estimation of the wild boar population in Southern Italian Apennines by Pellet Count Group technic. For this purpose, different maps of potential impact of wild boars in the Molise Region, were elaborated through the use of GIS programs. These maps were never been drawn up before for these territories and were applied to road accidents caused by wild boars, to the relevant correlations of the environmental variables and the ecological structures that drive the wild boars into the city through specific corridors and to the estimation of the wild boar population by Pellet Count Group technic. Considering the period in which the thesis was carried out and the limitation of movement linked to the pandemic situation, other experimental protocols based on field trials were not carried out. On the other side, a review concerning the behaviour to changing conditions of wildlife species in urban areas during lockdown was planned. This study concerned the effects on wildlife and ecosystems that are related to human activities, possible interactions between humans and wildlife, and the perspectives on wildlife and ecosystem management going forward.

CHAPTER 1
The wild boar (*Sus scrofa L.*).
Italian biology and context.

1.1 Fundamental elements of wild boar biology (*Sus scrofa*), taxonomy and general characteristic.

Figure 1.1 Integrated Taxonomic Information System – Report, 2022

Kingdom	Animalia – Animal, animaux, animals
Subkingdom	Bilateria
Infrakingdom	Deuterostomia
Phylum	Chordata – cordés, cordado, chordates
Subphylum	Vertebrata – vertebrado, vertébrés, vertebrates
Infraphylum	Gnathostomata
Superclass	Tetrapoda
Class	Mammalia Linnaeus, 1758 – mammifères, mamífero, mammals
Subclass	Theria Parker and Haswell, 1897
Infraclass	Eutheria Gill, 1872
Order	Artiodactyla Owen, 1848 – artiodactyls, porco do mato, veado, cloven-hoofed ungulates, even-toed ungulates
Family	Suidae Gray, 1821 – hogs, pigs
Subfamily	Suinae Gray, 1821
Tribe	Suini Gray, 1821
Genus	Sus Linnaeus, 1758 – pigs
Species	Sus scrofa Linnaeus, 1758 – wild boar, pig, pig (feral), Wild Boar
Subspecies	Sus scrofa algira Loche, 1867
Subspecies	Sus scrofa attila Thomas, 1912
Subspecies	Sus scrofa cristatus Wagner, 1839
Subspecies	Sus scrofa davidi Groves, 1981
Subspecies	Sus scrofa leucomystax Temminck, 1842
Subspecies	Sus scrofa libycus Gray, 1868
Subspecies	Sus scrofa majori De Beaux and Festa, 1927
Subspecies	Sus scrofa meridionalis Forsyth Major, 1882
Subspecies	Sus scrofa moupinensis Milne-Edwards, 1871
Subspecies	Sus scrofa nigripes Blanford, 1875
Subspecies	Sus scrofa riukiuanus Kuroda, 1924
Subspecies	Sus scrofa scrofa Linnaeus, 1758
Subspecies	Sus scrofa sibiricus Staffe, 1922
Subspecies	Sus scrofa taivanus (Swinhoe, 1863)
Subspecies	Sus scrofa ussuricus Heude, 1888
Subspecies	Sus scrofa vittatus Boie, 1828

The order of the Artiodactyls embraces the set of ungulate mammals (that is, provided with hooves) whose limbs rest on the third and fourth toes; the second and fifth toes, smaller than the two central fingers, are inserted higher up on the limb (Figure 1.1). To the Artiodactyls belong 9 families, 81 genera and 211 species that include animals apparently very different from each other such as camels and llamas, deer, giraffes, gazelles and wild boars. (Nowak 1991), Figure 1.2.

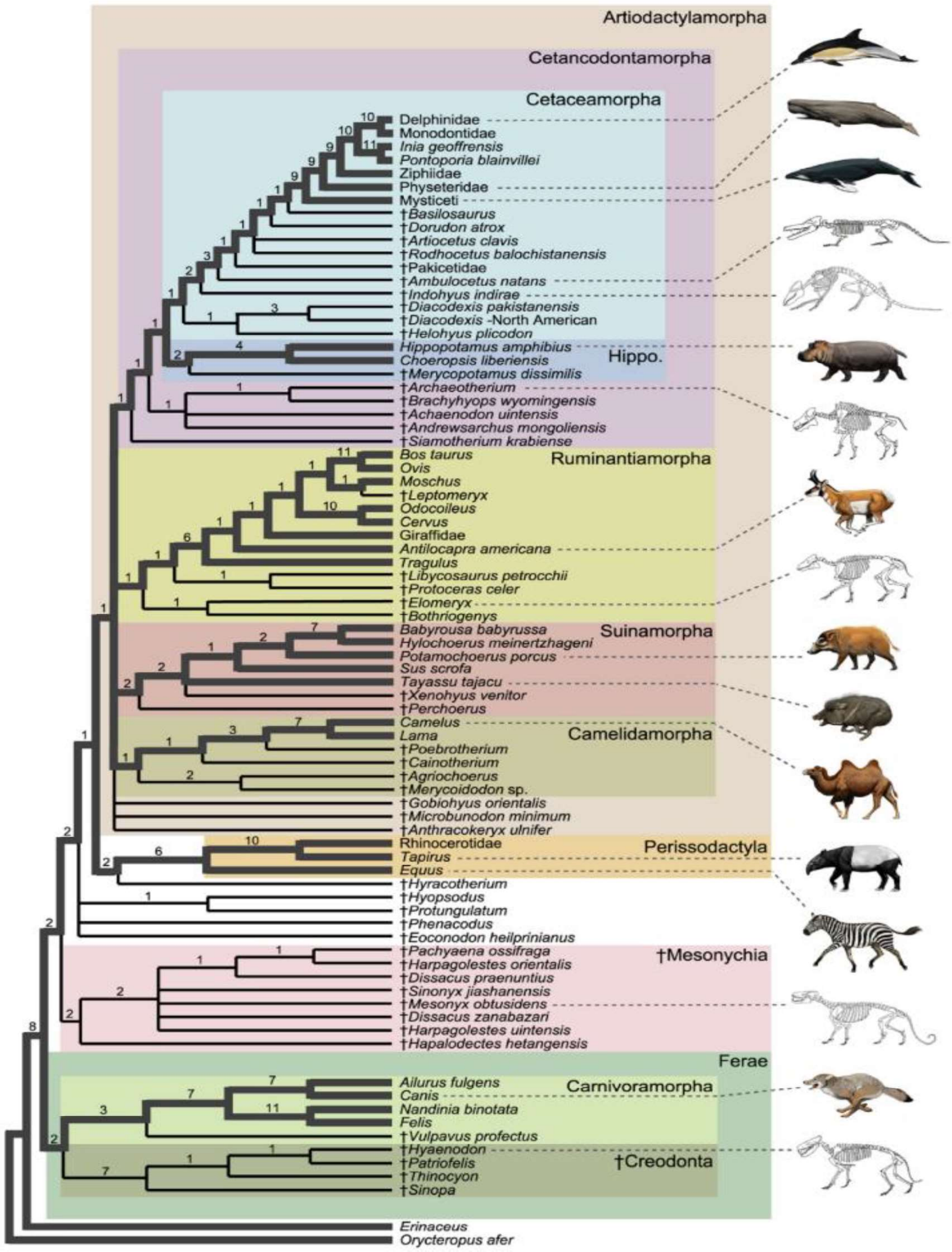

Figure 1.2 Relationships of Cetacea (*Artiodactyla*) (Michelle Spaulding, 2009)

The family of Suidae, to which the wild boar belongs, includes 5 genera and 9 species. The members of this family are medium in size and have relatively short limbs, stocky body, short neck and head constituting one third of the body length (Heptner et al., 1988, Figure 1.3) ending in a cartilaginous, rounded and very mobile disc called griffin (nose) Figure 1.4.

Figure 1.3 Legs of a wild boar

Figure 1.4 Disc called griffin (nose)

The griffin, at the centre of which the nostrils are located, is highly innervated and is used by all Suidae to dig into the ground in search of food such as bulbs, roots and invertebrates. The wild boar is well adapted for digging: head acts as a plow, while powerful neck muscles allow the animal to upturn considerable amounts of soil (Marsan and Mattioli, 2013): digs 8-10 cm into frozen ground and upturns rocks weighing 40-50 kg (Baskin and Danell, 2003). The skin is thick and covered with sparse, bristly hair (bristles). In some species, including wild boar, the animals possess a thick winter coat, consisting of shorter and finer hairs, a mane and a tuft of hair on top of the tail. Suids have a simple stomach and in females the number of breasts varies from two to twelve, and the young are born with a camouflage coat with longitudinal stripes that lose at the first change of the hair. (Massei and Genov, 2000). The general appearance of the wild boar is that of a robust animal, with relatively short limbs and tail and a more developed facial part of the skull than the front (Nobile, 1987). The foreleg, especially in males, is taller than the posterior one and the muzzle appears short and stocky in males and more elongated in females. In profile, the ventral tuft of hair indicates the male sex, while the lactating females show a row of more or less enlarged breasts. In adult males, canines are much more developed than those of females. Although the general shape of the body is stockier and more robust than that of other ungulates, the wild boar can run, trot, jump, crawl with its belly on the ground and elongated limbs and swim, thus demonstrating a remarkable and unexpected agility.

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Figure 1.5 Adult male wild boar

Figure 1.6 Striped wild boar cubs

Adult size and weight largely determined by environmental factors:

- **Western and Central Europe:**

Males:

Weight: 75–100 kg

Height: 75–80 cm in shoulder height and 150 cm in body length

Largest males weigh up to 200 kg

Females

Weight: 60–80 kg

Height: 70 cm in shoulder height and 140 cm in body length

Largest females weigh up to 120 kg

- **European Mediterranean regions:**

Males:

Weight: 50 kg

Females:

Weight: 45 kg

Height: 63–65 cm in shoulder heights of 63–65 cm

- **Eastern Europe**

Males:

Weight: 110–130 kg

Height: 95 cm in shoulder height and 160 cm in body length

Large males can reach 270 kg, measuring 110–118 cm in shoulder height

Females:

Weight: 95 kg

Height: 85–90 cm in shoulder height and 145 cm in body length.

The species is characterized by sexual dimorphism and the males have larger dimensions than the females (Figure 1.5). Weight differences only become evident after the first year of age, when weight growth slows down in females and remains high in males (Gaillard et al. 1993). Males are 5–10% larger and 20–30% heavier than females. Males sport a mane running down the back (particularly apparent during autumn and winter) (Marsan and Mattioli, 2013). During the breeding season males develop a coating of subcutaneous tissue (2–3 cm thick), extending from shoulder blades to the rump (protecting vital organs during fights). The availability of food has a considerable influence on the average weight of wild boars: in fact, if the preferred foods are lacking, the body weight can undergo a drastic reduction. The coat is made up of two types of hair: the bristles of the so-called "giarra", dark and thick, which fray at one end into yellowish-white tips, and the thinner and thicker hairs of the "wad". Both sexes have a mane made of up to 15 cm long bristles, which start from the top of the head and reach the middle of the body. In case of danger or during fights between males, the mane rises and contributes to making the animal appear larger. The color of the coat changes with age: the young are born with a light brown livery, furrowed with longitudinal cream-colored stripes (Figures 1.6, 1.7), which is replaced at the age of three to four months by a reddish coat. In adults, the coat can range from brown to dark gray. The sides of the muzzle often take on the so-called "frost" color gray-silver. The mantle is shed in late winter-early spring. The summer coat is made up of very short bristles, a few millimeters long, with whitish ends that will continue to grow until autumn when the wad also appears to isolate the body of the boar from the harsh winter.

Figure 1.7 Adults with small streaked wild boar

A wild boar is born with 8 milk teeth and as an adult it has 44 definitive teeth, 22 upper and 22 lower. The canines, called “coti” (the superior ones) and “defences” or “fangs” (the inferior ones), are continuously growing and in males they are much more developed than in females. (Figure 1.8). The continuous rubbing of the defences and whetstones serves to keep these teeth sharp and ready to be used in fights with other males or to defend against predators (Figure 1.9).

Figure 1.8 Wild boar skull

Figure 1.9 Wild boar defences

The most developed senses in wild boar are smell and hearing, while sight is less acute than in other ungulates. The sense of smell plays a very important role in recognizing conspecifics and predators and in searching for food. During the search for food, the wild boar often proceeds with its nose a few centimetres above the ground, continuously sniffing the ground: this innate behavior, which has remained unchanged in the domestic descendants of the wild boar, is exploited by those who train pigs to search for truffles. (Massei and Genov, 2000).

1.2 Area and geographical distribution in Europe and Italy

The wild boar (*Sus scrofa*) is among the most widely distributed large mammals in the world (Oliver et al., 1993). The range of the *Sus scrofa* species covers a large part of the Eurasian continent and part of northern Africa. (Figure 1.10). At present there are 11 new proposed wild boar species.

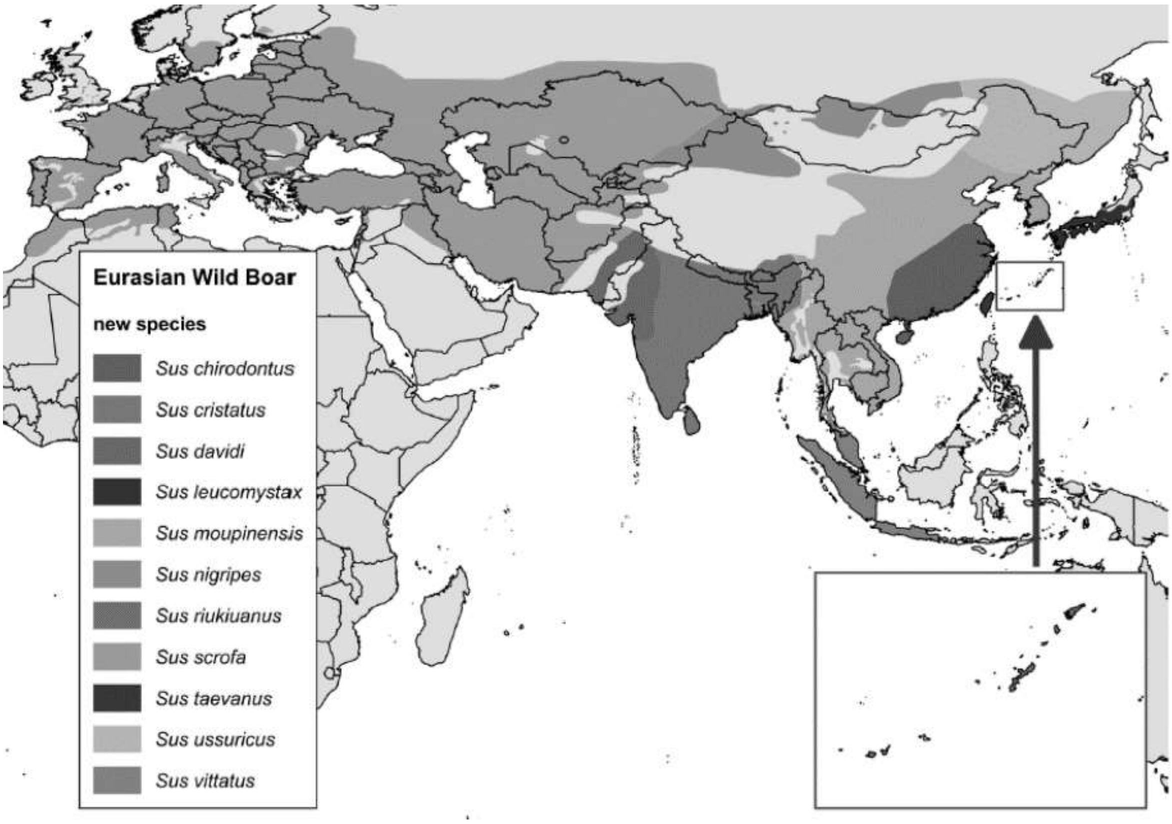

Figure 1.10 Distribution range of wild boar in Europe

Occurrence is yet to be well assessed and for this reason there are some gaps in the map. The phylogenetic studies in the geographical regions (Larson et al. 2005) show that the overall geographical distribution of some of the mtDNA CR clades falls within the range of some proposed new wild boar species (e.g. *S. leucomystax, S. riukiuanus, S. taevanus, and S. chirodontus*). This could be the basis for a test to clarify if those genetic profiles are species-specific. However, this new classification needs to be tested using comprehensive sampling from genetic, comparative chromosome painting and morphometrics approaches to better understand the complexity of wild boar taxonomy and level of hybridization through its large range. This validation is important because the new classification could have an impact on defining priorities for conservation of the new proposed wild boar species. The species colonized many areas of the American Southern continents and some Pacific islands. The species originated in South East Asia during the Early Pleistocene (Chen et al., 2007) and its natural range extends from Western Europe and the Mediterranean basin to Eastern Russia, Japan and South-east Asia (Sjarmidi and Gerard, 1988). Its distribution continues to increase worldwide. The species is extremely adaptable, with an enormous reproductive capacity, and can be found throughout a large spectrum of habitat types, ranging from semi-arid environments to marshes, forests and alpine grasslands (Sjarmidi and Gerard, 1988). One of the reasons for the wider spread of wild boars populations has been for their meat; wild boar farms have been established in countries where the species were hunted longtime till the extinction. The wild boar population was not present in Sweden ten years ago, but now 150.000 individuals are present the country (Magnusson, 2010). The UK also has a boar population that appeared for the first time 300 years ago (Rozycka et al., 2015). Due to its extensive distribution, high numbers and considerable adaptability, the IUCN has classified the wild boar as a species of least concern and it is considered an invasive species in certain areas where it has been introduced (Bieber and Ruf, 2005) (Figures 1.11, 1.12).

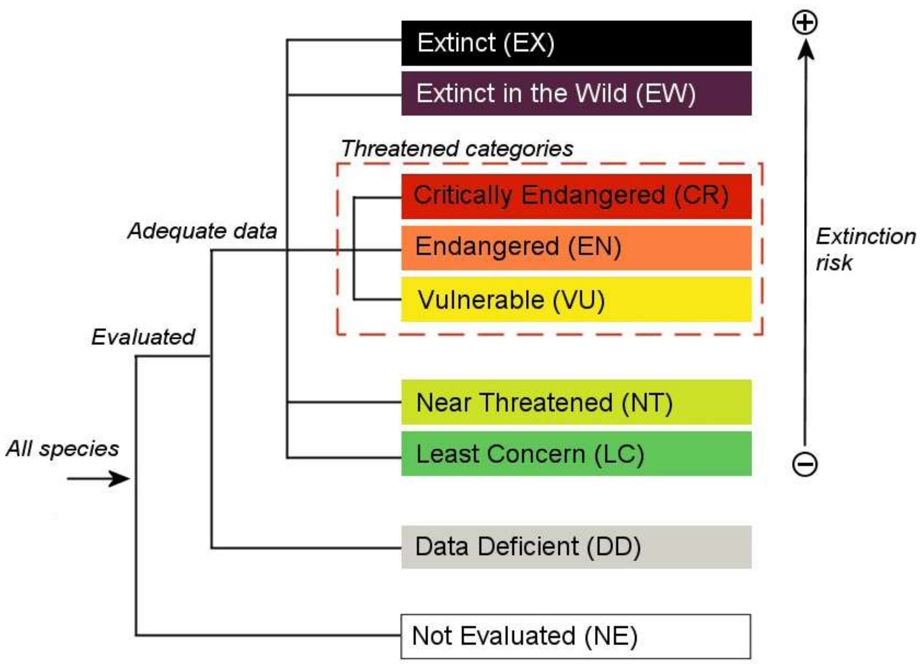

Figure 1.11 IUCN classification

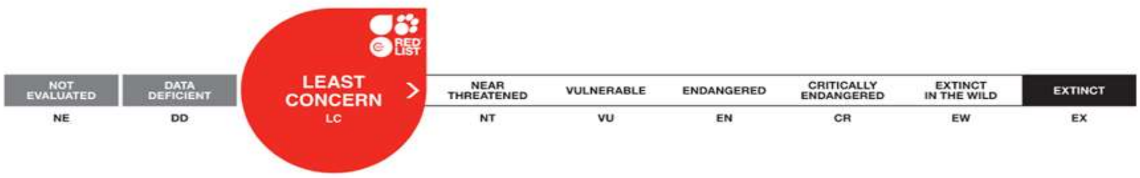

Figure 1.12 *Sus scrofa*. The IUCN Red List of Threatened Species (Keuling and Leus, 2019)

The species has developed several subspecies. Wozencraft (2005) describes 16 subspecies, divided in four regional groups (Western, Indian, Eastern, and Indonesian) (Figure 1.13).

Figure 1.13. Western, Indian, Eastern, and Indonesian regional groups where the 16 subspecies are described.

In Europe, the geographic distribution of wild boar appears to be limited mainly by adverse climatic conditions, such as very harsh winters, with a high number of days of heavy snow that does not allow the animals to move around and find enough food (Massei and Toso, 1993). In historical times the wild boar was found in most part of the Italian territory. Starting from the end of the 1500s, its presence gradually diminished due to the direct pressure of man; it reached the extinction on a local scale between the seventeenth and nineteenth centuries in Trentino Alto Adige, Friuli Venezia Giulia and Romagna. The negative peak was reached during the Second World War, with the disappearance of the last populations in the Adriatic regions. After the war there was an inversion of this phenomenon, with a progressive expansion of the distribution areas and subsequently a real demographic boom, particularly in the last forty years, which led to the current situation (Monaco et al. 2003). The great adaptability and the ability to exploit environments heavily modified by man have allowed the wild boar to undergo a real demographic explosion in the last decades. The possible causes of are referred to:

- Abandonment of the countryside by man, which has caused an improvement in environmental conditions favorable to the species;
- Re - immission of individuals;
- Artificial foraging;
- Lack of natural predators;
- Limitation of hunting pressure;
- High reproductive potential;
- Tendency towards nomadism;
- Milder climatic conditions.

The most important factors that probably favoured the reappearance of the wild boar in Italy and its subsequent demographic explosion were the recovery of wooded areas from agricultural and pastoral areas, the depopulation of vast swathes of the Apennines with the consequent decrease in human pressure and the introduction of large animal contingents starting from the 1950s. The framework of knowledge about the density of wild boars Italian populations and its evolution is very lacking as a consequence of a management of the fauna heritage which, with few exceptions, lacks the indispensable technical-scientific bases and an adequate and programmed intervention management (Massei, 1993). The distribution of wild boar in Italy currently covers a large part of the territory as shown in Figure 1.14. The areas with the highest density are those of the Alpine and Apennine ridges (Apollonio, 1988). In Emilia Romagna, as well as throughout the peninsula, the wild boar is the most widespread ungulate (Gellini et al. 2003). The populations of native wild boars are those of Castelporziano, Maremma and Sardinia Region, the rest are hybrid populations (Scandura et al. 2022). This species needs a control plan that defines more restricted management areas than the possibility of expansion of the species as a function of a careful evaluation of the relationships with the various local economic interests (Ravajoli et al., 1990).

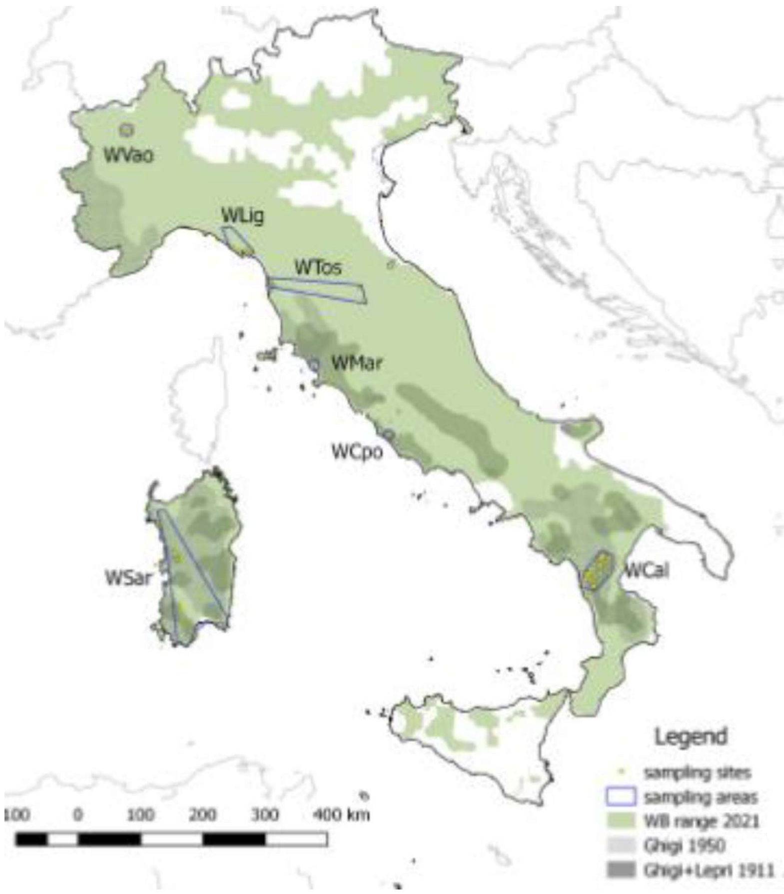

Figure 1.14 Distribution of wild boar in Italy (Scandura et al. 2022)

1.3 Wild boar habitat

The wild boar inhabits different kind of habitats (Heptner et al., 1988). Although it prefers temperate zones, the wild boar can live in the most varied environments and in regions characterized by very different climates and vegetation, thanks to a remarkable alimentary plasticity. The species has adapted perfectly to living in all countries where it has been introduced by man, from semi-arid environments to swamps, forests and alpine meadows (Sjarmidi et al., 1988). Among the few factors that limit the distribution of wild boar are the presence of water and the prolongation of heavy snow cover. Water is necessary for the mud baths that wild boars carry out in any season, and for drinking, especially in periods when the diet is relatively low in liquids. Snow is a limiting factor when it exceeds 30-40 cm and persists for many consecutive weeks: in these conditions, wild boars, with relatively short limbs compared to other ungulates, cannot move easily or find sufficient food (Marsan and Mattioli, 2013). The preferred environments of the wild boar include the Mediterranean scrub, the deciduous forests and the mixed forests of conifers and broad-leaved trees with dense undergrowth vegetation (Figures 1.15 a, b, c).


a


b


c

Figure 1.15 Ideal habitat of wild boars

The ideal habitat consists of an alternation of woods and meadows: woods with trees that produce high-energy fruits, such as acorns and chestnuts, and meadows that the wild boar digs with the griffin in search of larvae, insects and roots. In the absence of natural vegetation, this species is able to make perfect use of areas cultivated with cereals, grapes, sunflowers and potatoes, where food resources, represented by the crops themselves, are easily accessible. The high energy value of the crops, combined with the spatial concentration of these resources, means that wild boars tend to use the cultivated areas especially if these are located close to the forest and in relatively undisturbed areas. The use of different environments by wild boar seems to be particularly influenced by the availability of food resources. To reach an area temporarily rich in food, wild boars can make altitudinal "migrations", from the planes to the mountains, or move at a distance of tens of kilometres from the area in which they are located. The consistency and degree of humidity of the soil play an important role in habitat selection because the wild boar's diet is largely composed of underground food (insect larvae, tubers, roots) which are easier to unearth if soil conditions are favourable. Humid environments and cool areas are sheltered from the summer heat are therefore essential for this species. In winter, in fact, wild boars are protected by a thick coat and a thick layer of subcutaneous fat and do not seem to suffer from the cold; however, high temperatures can create hyperthermia problems. In the hot season, according to Saunders and Kay (1991), the preference of wild boars for humid and cool environments is explained by the fact that this species does not have sweat glands: therefore, the only way that wild boars have to maintain a correct body temperature is to take mud baths (Figures 1.16 a, b) and frequent environments that offer good plant cover to shelter from the sun.


a b

Figure 1.16 Wild boar mud bath

Another way to avoid the heat of summer days is to be active only during the night hours. The selection of habitat by the wild boar is also influenced by the sex, age and physiological state. For example, females with very young babies seem to choose an environment based on coverage, food availability and relative quiet, while young males mainly frequent areas rich in food resources (Massei and Genov, 2000).

1.4 Spatial ecology of the species

It is not clear whether the fact that wild boars are mainly nocturnal derives from a natural behavior, or if it is a condition imposed by hunting. The nocturnal habits of wild boars have to be connected exclusively to the disturbance of anthropogenic origin; but, on the other hand, the fact that these animals have poor eyesight, but a very developed hearing and smell sense, argues in favour of an adaptation to darkness. It is certain that in the areas where they are hunted, wild boars come into activity at dusk and go back to sleep at dawn (Boitani et al., 1994). However, it has been studied that animal move less at full moon, to escape predators and disturbances of anthropogenic activity (Gordigiani, 2021). The females have a behavior of marked fidelity to a certain number of preferred areas. Adult and sub-adult males show more exploratory behaviors by covering daily distances up to a maximum of 15 km. The movements of an individual generally remain within an area of 150 ha and almost all the movements of individuals in a population fall within an area of about 70.000 ha. It can be assumed that only a small part of the population, mainly sub-adult individuals who represent approximately 10% of the total, make major movements. This phenomenon derives from the expulsion of male individuals aged between 6 and 12 months from family groups, with the consequent phase of dispersion which leads to the transfer over greater distances than other age groups. The size of the displacement "*home ranges*" may vary according to the presence of natural predators or to an increased hunting pressure. The average size of seasonal displacements turns out to be smaller in those areas where previous limiting factors are absent or scarce (Munich et al. 2003). The time spent by wild boars in different types of activities varies greatly in relation to the season, the abundance of food, sex and the physiological state of each individual. (Massei and Genov, 2000), and its home ranges vary according to the season and activity (Gaudiano L., 2022).

1.5 Food ecology of the species

The wild boar is omnivore and, consequently, is able to use a wide spectrum of resources and, if necessary, to drastically modify its diet in relation to the availability of food in the different environments and in the various seasons. This dietary flexibility allows it to survive in the most varied environments and to adapt to the most diverse situations (Haptner et al., 1988). The wild boar has a simple stomach, unlike that of other ruminant ungulates consisting of four different parts and specialized for a plant-based diet. Compared to ruminants such as, for example, roe deer and deer, wild boar does not therefore appear to be as efficient in the use of grasses, leaves and other components of the vegetation, and its diet must be supplemented with proteins of animal origin or with highly energetic plant foods. It has in fact been shown that, although plants form an important part of the diet of this species, wild boars suffer from hunger and can die when they cannot feed on fruits or energy-rich foods. (Massei et al., 1997). Jezierski and Mircha (1975) calculated that a 50 kg wild boar must consume about 4.000 – 4.500 calories per day and that this requirement increases by 10% in females during pregnancy and breastfeeding (Marsan and Mattioli, 2013). In the case of scarce availability of foods, wild boars will eat tree bark and fungi, as well as cultivated potato, artichoke fields, maize, rapeseed, corn etc. Wild boars may occasionally prey on small vertebrates like new born deer fawns, leporids and galliform chicks (Marsan and Mattioli, 2013). A balanced diet and a sufficient intake of calories are essential to develop the population dynamics of wild boars, as they affect the age of the first calving, the total number of females participating in reproduction and the number of offspring per calving. Conversely, a low-calorie diet can lead to severe physical wasting and sometimes the death of a sizable portion of the population. (Massei et al. 1997). The amount and quality of food resources influence the mating period, which falls in autumn in the years of high food availability and moves more and more towards winter in years of food shortage. While young wild boars use food resources for growth, adults store the energy obtained from food as cover fat. The boar's diet consists of wild fruits, herbs, bird eggs, tubers and rhizomes, insect larvae, molluscs, earthworms, small vertebrates and carrion. Favourite natural foods include acorns and chestnuts, but also tubers, bulbs and roots that the wild boar obtains by digging the ground with the snout (Figure 1.17) (Heptner et al., 1988).

Figure 1.17 Wild boar snout

A large part of the diet of this species is in fact made up of foods found underground: a meadow visited by a group of wild boars in search of insect larvae or roots appears as a carefully plowed field at a depth that can reach 40 cm (Figures 1.18 a, b).

a

b

Figure 1.18 Signs of wild boar activity: typical of "rooting"

Given the importance that underground foods play in the boar's diet, it is easy to understand that if the soil is hardened by frost or drought, part of the food suddenly becomes - and sometimes for many consecutive weeks - difficult or even impossible to find. If such a situation continues for a few weeks, wild boars go hungry and weaker individuals (young and pregnant or lactating females) can die. The results of numerous studies conducted on the feeding of wild boar agree that foods of plant origin account for most of the ingested volume. The proportion of animal food present in the wild boar's diet is extremely variable both when comparing different populations, and within the same population in consecutive years. The variety of foods of animal origin and the fact that in the absence of their favorite food, wild boars can turn to a variety of alternative resources, confirm the extreme food flexibility of these animals. When wild boars feed on acorns and carbohydrate-rich fruits, the protein scarcity of these foods could represent a problem (Monaco et al, 2003).

The proportion of food of animal origin in the wild boar's diet rarely exceeds 10% of the ingested volume (Figure 1.19) but this food is often present in the majority of samples taken from stomachs and faces.

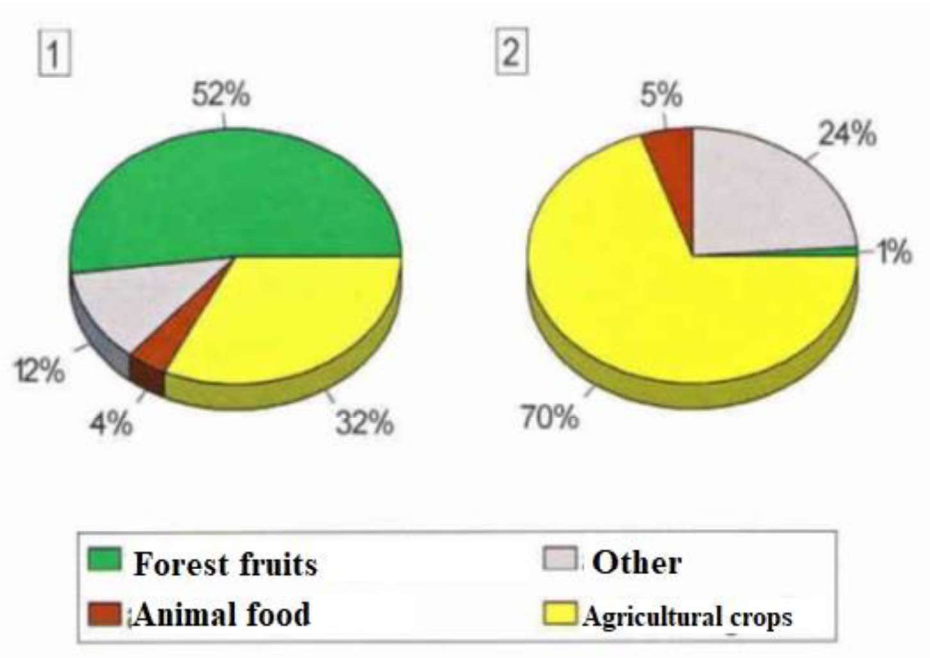

Figure 1.19 Typical subdivision of the wild boar diet in periods of low acorn and beech tree production (Monaco et al, 2003)

This indicates that animal proteins, even if used in minimal quantities, play a fundamental role in the diet of wild boars. (Schley, 2003). A typical feeding behavior of wild boar, and not found in other ungulates, is to chew plant food, for example ears of wheat or licorice roots, which is not ingested and which is found on the ground in shapeless masses, but from which presumably animals get a certain amount of energy. Crops, such as cereals, legumes, grapes, sunflowers and potatoes are an excellent alternative to the scarcity of natural food for wild boar. Furthermore, unlike natural foods whose availability can fluctuate widely, cultivated plants represent an abundant food source and always concentrated, always available and with a high energy value (Massei and Toso, 1993). Wild boar's favourite crops include potatoes, sunflowers, sugar beets, grapes, corn and autumn-winter cereals such as wheat, barley and oats. Some French researchers (Bouldoire and Vassant 1989) have pointed out that, in the absence of berries, the percentage of cultivated plants could rise from 32 to 70% of the ingested volume and the fact that wild boars are able to survive perfectly even in heavily populated areas it once again demonstrates the extreme adaptability of this species. (Massei and Genov, 2000).

1.6 Wild boar impact and damage assessment

If we consider the typical characteristics of the species, it is easy to understand the extent of the impact of the wild boar not only on plant communities and natural zoocoenosis, but also on anthropogenic systems such as agricultural ecosystems. The wild boar is able to live in any system that allows it to satisfy three basic needs:

1. availability of food

2. plant cover sufficient to provide shelter

3. availability of water

The great adaptability of the species allows it to meet these needs in different types of environments, above all by modifying its diet according to the resources available in a specific area. The impact of the wild boar derives mainly from its behavior and eating habits and we can generally divide it into impact on forest systems and zoocoenosis, and impact on man-made systems. In Europe, the wild boar is a major cause of damage to agricultural crops (Schley et al., 2008) and the occurrence of crop damage by wild boars has increased dramatically over the past few decades (Amici et al. 2012). As a result, there has been an increase in human-wildlife conflicts, increased compensation expenditure by both private entities and governments, as well as increased risk to natural ecosystems (Amici et al., 2012). The increasing numbers and negative impact on agricultural land is part of the reason why the wild boar is considered a pest species in many parts of the world (Schön, 2013). Many European countries now compensate farmers for wildlife damage. These compensations have been increasing over the years and currently tens of millions of Euros are paid out annually by governments of EU Member States in claims by farmers and land users for loss of income and damages (Schlageter and Haag-Wackernagel, 2012). From an economic point of view, the wild boar is the wild species that causes the greatest damage to agricultural production in many territories, even apparently different from each other. Wild boar feeds on crops such as; corn (*Zea mays*) (Herrero et al., 2006), potatoes (Solanum tuberosum), beans (*Phaseolus spp*.), peas (Pisum spp.), sugar beets (Beta spp.) (Schley and Roper 2003) and cereals (Herrero et al., 2003), although the trichotomous cereals are less preferred (Schley et al., 2008). In Italy, the costs arising from the execution of compensation and prevention of damage caused by the species, in various local contexts, they appear to have a significant impact on the financial resources that the administrations delegated in the field of wildlife management can rely on.

As already mentioned, the areas where the problem is most recurrent and economically relevant are those of transition between the forestry structures and the open areas affected by agricultural crops. These situations are recurrent in most of the Italian area occupied by the species, namely the Apennine ridge and some pre-Alpine areas. Among the crops most sought after by wild boar, corn, some weeding crops such as potatoes, sunflowers, sugar beets and peas, autumn-winter cereals such as wheat, barley, oats, rye, pastures and vineyards. The attribution of responsibility for damage to wild boar rather than to other species does not normally consist of a problem given the typical signs of presence left by the Suide in feeding places, such as footprints, excavations and made. (Massei G., S. Toso, 1993). The interactions that a wild boar population contracts with natural phytocoenosis, as well as with agricultural ecosystems, vary significantly not only from area to area but also, within the same area, if considered in subsequent years. The relationship of the wild boar with agricultural ecosystems is resolved in a direct impact, due to the removal of the different cultivated species, and in an indirect action, caused by trampling and excavation that damage the plants by exposing their roots. The resulting damage can have a significant impact on human activities, which is perhaps the reason why this aspect is more studied than others. It is appropriate to identify the factors which, interacting with the wild boar population, direct their food choices towards crops such as cereals, sunflowers, potatoes, vine yards. The high energy value of the latter, combined with the spatial concentration of the resources themselves, partly justifies the preferences of the Suidae, which tend to optimize the cost / benefit ratio. Some research carried out in this regard concludes that the basic factor that influences the preference for crops is above all the lack of sufficient attractive food in the woods at certain times. In environments heavily handled by man, such as agricultural ecosystems, it is always appropriate to consider these aspects of wild boar biology to cope with the periodic "invasions" of animals also conditioned by specific endogenous rhythms. Overabundance of one species typically has a negative impact on the overall biodiversity of a region (Koons, D., 2014). Wild boar feed on whole plants or on vegetative parts, such as fruits, bulbs, and tubers. This way, wild boars may affect the abundance and richness of a plant species (Singer et al., 1984). Rooting is the major cause of disturbance to plant communities (Hone, 2002). Assessing the impacts of wild boar on species richness is not straightforward however (Massei and Genov, 2004). Wild boar feed on a wide range of vertebrate and invertebrate species. Animal matter is found in up to 94% of the stomachs analysed, (Baubet et al., 1997). Invertebrates, such as insect larvae, earthworms, and snails are often reported as a staple food in the diet of wild boar. In Europe, the numbers and distributional range of most ungulate species (deer and wild boar in particular) are expanding (Apollonio et al., 2010). The wild boar population is increasing rapidly right across Europe, which is reflected in the traffic accident statistics where the number of reported wild boar-vehicle accidents has increased during the last years (Olsson, 2007). Such expansion produces conflicts between wildlife and human activity. Whether or not directly managed by humans, wild animals suffer impacts from our activities in direct loss of habitat, impacts on grazing quality, loss of ecological connectivity through the proliferation of road systems, and an increasing number of animals are killed and injured on roads. Collisions of ungulates with motor vehicles are also another impact of wildlife on humans which has shown a steady increase (Langbein et al., 2011). Collisions of ungulates with motor vehicles are also another impact of wildlife on humans which has shown a steady increase (Langbein et al., 2011). Road collisions involving wild boar represent an increasing problem in Italy, although data are limited. Ponzetta et al. (2011) reports that wild boar is the main species involved in road accidents, as in the period 2001-2009 in Tuscany, 1.355 WBCs were recorded out of a total of 3.290 ungulate-vehicle collisions. In the Viterbo Province (Lazio Region), instead, 46 collisions involving wild boar, in the period 2003 to 2006, were recorded on a total of 60 UVCs (Primi et al*.*, 2010).

1.7 Wild boar zoonosis

Wild boars are known to be responsible for the spreading of several diseases to both livestock and people (Rossi et al., 2011.). During the last 30 years the number of disease notifications in wild boar in Europe has significantly increased (Boadella et al., 2012) showing clear correlations between disease intensity and persistence and wild boar abundance. Here we provide a brief overview of the most prevalent zoonotic and other transmissible diseases.

- **Hepatitis E**

Swine hepatitis E virus (HEV) is considered to be a new zoonotic agent due to its close genomic resemblance to the human HEV. The disease causes asymptomatic infection in swine; however, it is a public health concern, causing acute hepatitis in humans of varying severity. In humans, Hepatitis E is a liver disease caused by the hepatitis E virus.

- **Classical swine fever (CSF)**

Hog cholera or swine plague, is still one of the main viral diseases in pigs, both in Europe and worldwide (Pejsak et al., 2014). Wild boar populations play a crucial role in the spread as the reservoir of CSF in Europe. Swine fever causes fever, skin lesions, convulsions, and usually (particularly in young animals) death within 15 days. A small fraction of the infected pigs may survive and are rendered immune. (Greiser-Wilke and Moennig, 2004).

- **African Swine Fever (ASF)**

The recent emergence and spread of African swine fever (ASF) in Eastern Europe is perceived as a serious risk for the pig industry in the European Union (EU). ASF has recently appeared in several European countries, with cases linked to the movement of native wild boar (Galindo and Alonso, 2017) Figure 1.20. ASF is devastating for the pork industry, causing massive losses of animals due primarily to enforced culling and mortality of infected animals (Guinat et al., 2016). Further economic loss from trade restrictions can be severe (Guinat et al., 2016). The disease is fatal in almost 100% of cases, it is highly transmittable and there is currently no vaccine (Galindo and Alonso, 2017). The disease is transmitted through faeces, urine, or nasal secretions from sick boar contaminate soil or plant material, which dog walkers or mushroom pickers, for example, might carry out of the forest. Hunters who kill an infected animal pose a bigger risk, as blood is highly infectious. Besides wild boar transmission, there are three other major means the disease can spread: transport fomites (objects or materials which are likely to carry infection i.e. vehicles or clothing that have been in contact with an infected animal), through legal pigs, and via illegal imports (Mur et al. 2014).

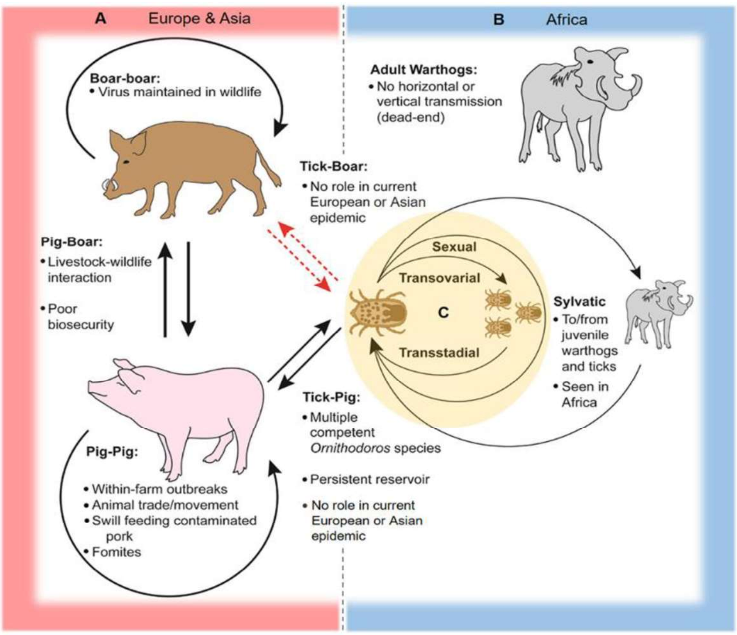

Figure 1.20 Schematic of ASFV transmission cycles. (Gaudreault N. et al, 2020)

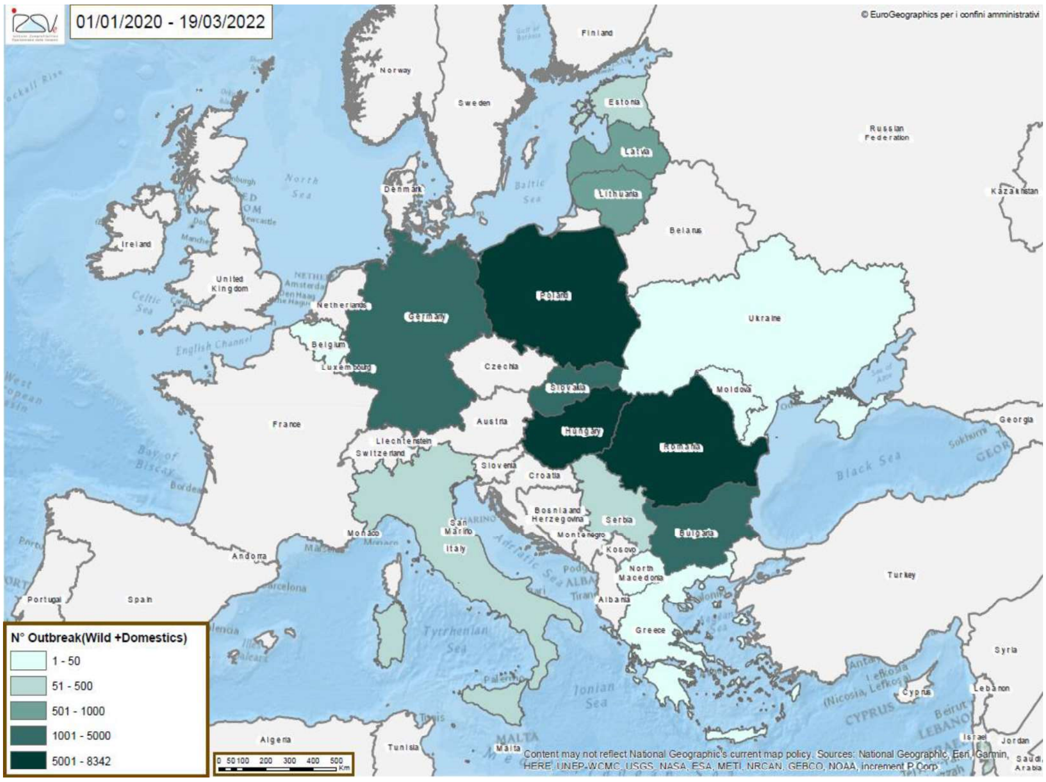

Figure 1.21 ASF in Europe (Italian Union of Veterinary Public Medicine, SIVemP, 2022)

In Italy ASF was eradicated in the Sardinia Region with few outbreaks; recently it was observed in the territories of the Piedmont Region and the Liguria Region (Figure 21, 22).

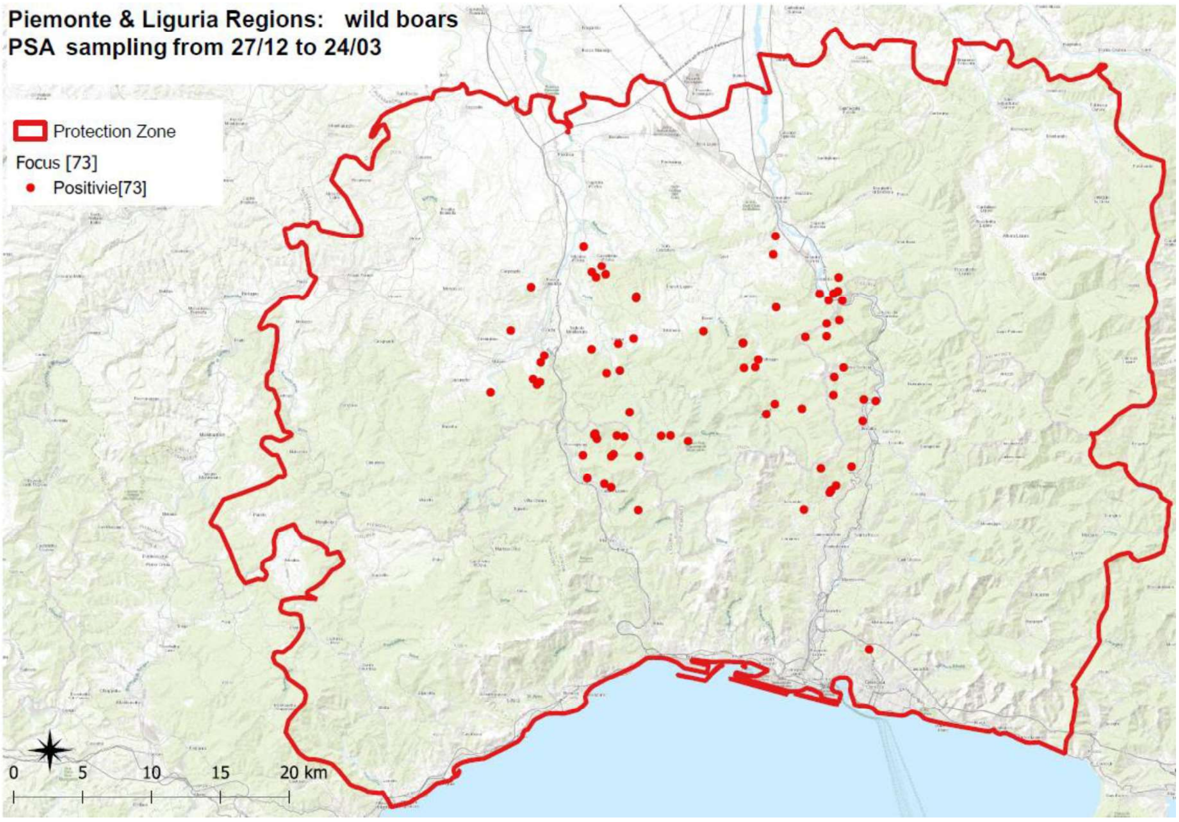

Figure 1.22 Map of the Experimental Zooprophylactic Institute of Piedmont, Liguria and Valle d'Aosta, 24/03/2022.

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CHAPTER 2
The GIS (*Geographic Information System*) and its use in wildlife and land management

2.1 The Geografic Information System (*GIS*)

A GIS is a tool for making and using spatial information. GIS techniques are any set of manual or procedures used for storing and manipulating georeferenced data, through a database in which most of the data is spatially indexed and on which a set of procedures operates to answer questions relating to their attributes space (Aronoff,1995). GIS and spatial analyses are concerned with the quantitative location of important features, as well as properties and attributes of those features. Each GIS user may decide which features are important, and which attributes are worth recording. A computerized data management requires a minimum knowledge of different data and related factors, and, perhaps above all, the spatial arrangement of these factors. A GIS helps to analyse these spatial relationships and interactions. A GIS is also particularly useful a view spatial data and report the results of the spatial analysis. In many cases GIS is the only way to solve spatially correlated problems. (Widodo, 2021). Thematic data within a GIS must be structured in such a way as to have a correct predisposition to adapt to the spatial information previously inserted; many GIS databases are associated with vector primitives. This connection is based on categories, i.e., identifiers that are unique to the elements that you want to relate. Spatial data organization, analyses and delivery are widely applied to improve life. The GIS software designed for the writing of the thesis provide a management service of database internal to the program, but they are also able to connect to a database external. GIS help to identify and address environmental problems by providing crucial information on where problems occur and who are affected by them. GIS help to identify the source, location, and extent of adverse environmental impacts, and may help to devise practical plans for monitoring, managing, and mitigating environmental damage (Bostad, 2016).

2.2 Organization and structure of a GIS

A GIS is composed of hardware, software, data, humans, and a set of organizational protocols. These components must be well integrated for effective use of GIS, and the development and integration of these components is an iterative, ongoing process. The selection and purchase of hardware and software is often the easiest and quickest step in the development of a GIS. Data collection and organization, personnel development, and the establishment of protocols for GIS use are often more difficult and time-consuming endeavours. (Rusko, 2010). (Figure 2.1).

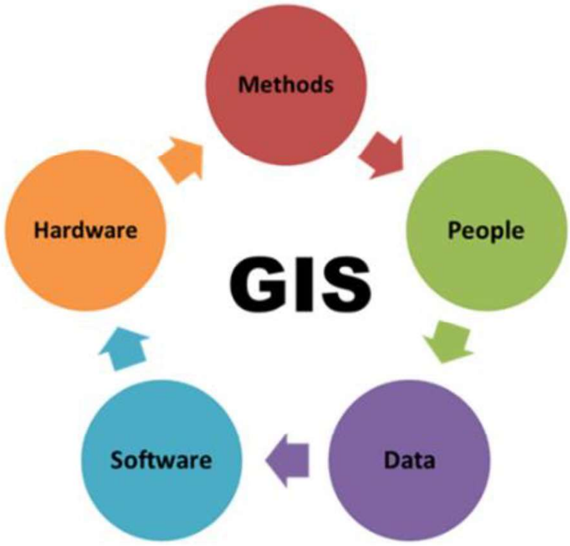


Figure 2.1 GIS composition

2.3 Data types in the GIS environment

Data in a GIS represents a simplified view of physical entities, the roads, mountains, accident locations, or other features we wish to identify. Data includes information on the spatial location and extent of the entities, and information on their nonspatial properties. Each entity is represented by a spatial feature or cartographic object in the GIS, and so there is an entity–object correspondence. Because every computer system has limits, only a subset of essential characteristics is recorded. Essential characteristics are subjectively chosen by the spatial data developer. No one abstraction is universally better than any other, and the goal of the GIS intended use at the desired level of detail and accuracy. (Azzam et al., 2013). A spatial data model (Figure 2.2) may be defined as the objects in a spatial database plus the relationships among them. The term “model” is fraught with ambiguity because it is used in many disciplines to describe many parameters. Here the purpose of a spatial data model is to provide a formal means of representing and manipulating spatially referenced information.

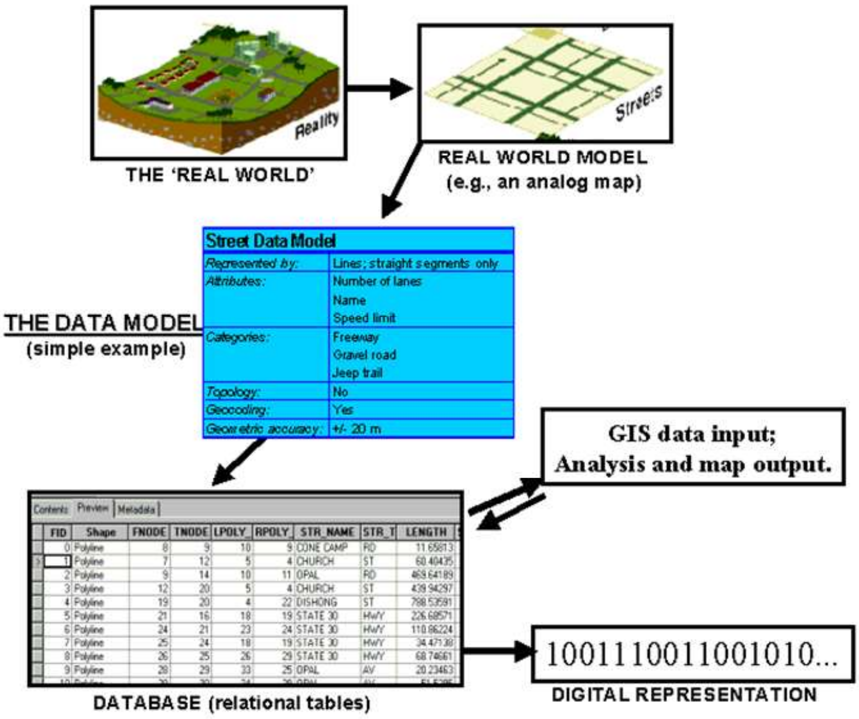


Figure 2.2 The modelling process of the spatial data.

The real world is described by the data model. The "database" is part of the resulting data structure (how the data model gets implemented in a digital computer). (Kraak, 2000). GISs deal with geographic data primarily related to features of the earth or related to human activities on those features. Geographic data are collected from the real world and are used to facilitate decision making and solve problems that relate to geography. Compared with other types of data, geographic data are geographically referenced as geographic information maps to real-world coordinates. Geographic data may be represented by descriptive elements denoting what they are and graphical elements denoting what they appear like, as well as their spatial relationship to one another. Geographic information may be temporal (carrying a specific date or time), thematic (carrying an event in history), or spatial (carrying a geographical region), and GISs primarily specialize in spatial geographic information. Data are bodies of facts or figures systematically gathered for a specific purpose. Data include linguistic expressions, symbolic expressions, mathematical expressions, signals, and statistics.

Information is data that have been processed into a meaningful form that is valuable to decisionmakers. The difference between data and information is that not all data are useful information (i.e., data may be unsuitable for consumption by decision-makers) (Kraaak, 2000). In a data perspective, the organization of geographic data is based on their descriptive and graphical elements. Descriptive data are organized in terms of primitive data items that represent atomic instances of data. Data items are aggregated into records, tuples of related data items that map to a phenomenon in the real world. Related records form a data file; data files may be of different organizations. Data files with only one type of record forming a single level of organization are flat files, whereas hierarchical files are data files composed of a single type of record with nested repeating groups of items forming multiple levels of organization. The data, within a GIS, are georeferenced; georeferencing specifies each element or event that refers to a certain portion of the earth's surface. They represent real world phenomena as well are defined through:

- Position information with respect to a specific reference system and known coordinates;

- Attributes describing the characteristics of the data;

- Mutual spatial relationships (topological, directional, distance).

The coordinates are used to define the spatial location and extent of geographic objects. A coordinate most often consists of a pair or triplet of numbers that specify location in relation to a point of origin. The coordinates quantify the distance from the origin when measured along standard directions. Single or groups of coordinates are organized to represent the shapes and boundaries that define the objects. Coordinate information is an important part of the data model, and models differ in how they represent these coordinates. Coordinates are usually expressed in one of many standard coordinate systems. The coordinate systems are usually based upon standardized map projections that unambiguously define the coordinate values for every point in an area. Coordinates define location in two- or three-dimensional space. Coordinate pairs, x and y, or coordinate triples, x, y, and z, are used to define the shape and location of each spatial object or phenomenon. The GIS Spatial data refers to a Cartesian coordinate system, so named after Rene Descartes, the system's originator. Cartesian systems define two or three orthogonal (right angle, or 90^o) axes. Two dimensional Cartesian systems define x and y axes in a plane. In addition, the Three dimensional Cartesian systems define a z axis, orthogonal to both the x and y axes. The origin is defined with zero values at the intersection of the orthogonal axes. Cartesian coordinates are usually specified as decimal numbers that increase from bottom to top and from left to right. Two-dimensional Cartesian coordinate systems are the most common choice for mapping small areas (Burrough, 2015).

A GIS is able to receive and analyse all types of data, which can be divided into two general categories: the vector data type and the raster data type.

2.3.1 Vector data

A basic graphical element is the most basic unit of information organization in graphical data. The basic graphical elements are points, lines (arcs), and polygons (areas), as shown in Figure 3. In a GIS, these three elements may individually represent key geographic features or entities.

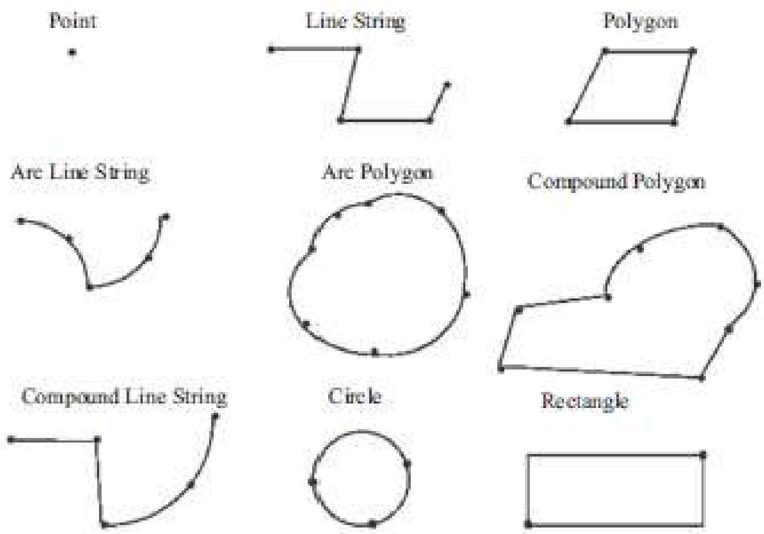


Figure 2.3 Basic graphical element of the vector data type

In the vector data type, the data are stored as points, lines, and polygons (Munafò, 2010). Less computer memory is used and better position accuracy is provided in relation to the raster format. The vector data type is useful for storing data that have discrete spatial boundaries, such as country borders, land parcels, and streets. The vector data type records and displays coordinates of objects with complete measurement accuracy in respect to ground measurements. The vector data type contains a lesser volume of information in relation to the raster data type for the same area. Additionally, it is easy to apply alphanumeric attributes to the defined schemes that express physical objects with points, lines, or polygons (Figure 2.3) (Kersting, 2002).

An information database record is associated with each vector element, which contains all the attributes of the object represented (Fugure 2.4 a). The main formats of vector type currently are: SHP, DXF, DWG, DGN, DWF, IGES, NTF, VPF, E00. The most common example of the relationship between spatial data - thematic data within a GIS program consists of a shapefile format. The format was developed by ESRI in the early nineties. Shapefiles record geometric data primitives, and each element has associated properties and attributes that describe it voices.

Its technical structure (Figure 2.4 b) is divided as follows:

- Main file .shp: describes the shape (point, line or polygon) with the list of its vertices (Figure 2.4 b);

- Index file .shx: contains the scan order starting from the first main file record;

- Database file .dbf: consists of various fields that contain the attributes from link to each record with a 1 to 1 relationship between geometry and attributes based on the record number.

- Optional prj file: keeps information on the coordinate system.

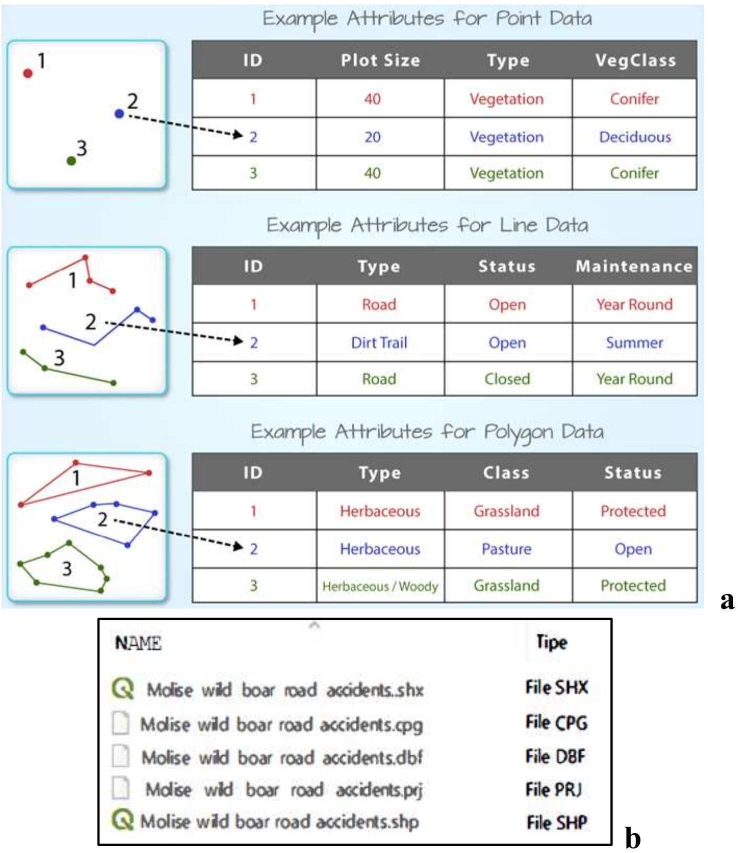


Figure 2.4 a) An example of the most common vector data model attributes (Leah, 2010); **b)** Example of a shapefile structure

The calculation of vector positions and intersections follows the principles of analytic geometry. For instance, a group of polygons may be used to represent a country on the world map (Dragicevic, 2004). Since points are dimensionless, they are used to represent point features in a GIS. For example, points may be used to denote coordinates of geographical features. Whether features are represented using points or another basic graphical element depends on the scale of the representation. For example, a park may be represented as a polygon in a large-scale representation, whereas in a smaller-scale representation, it may be denoted by a point (symbol). Lines represent linear features such as boundaries, contours, and roads. Area features represent objects that contain breadth and length, and their boundaries delineate homogeneous properties, such as soil type in a GIS. In a vector data model, the geographic data in a GIS are represented by such basic graphical elements. In the vector model, data are organized by themes or layers. Examples of such layered spatial data in a GIS would be a layer of soil composition, of topographical data, of land parcel, telecommunications networks, and other information, as shown in Figure 2.5 (Kolios, 2017).

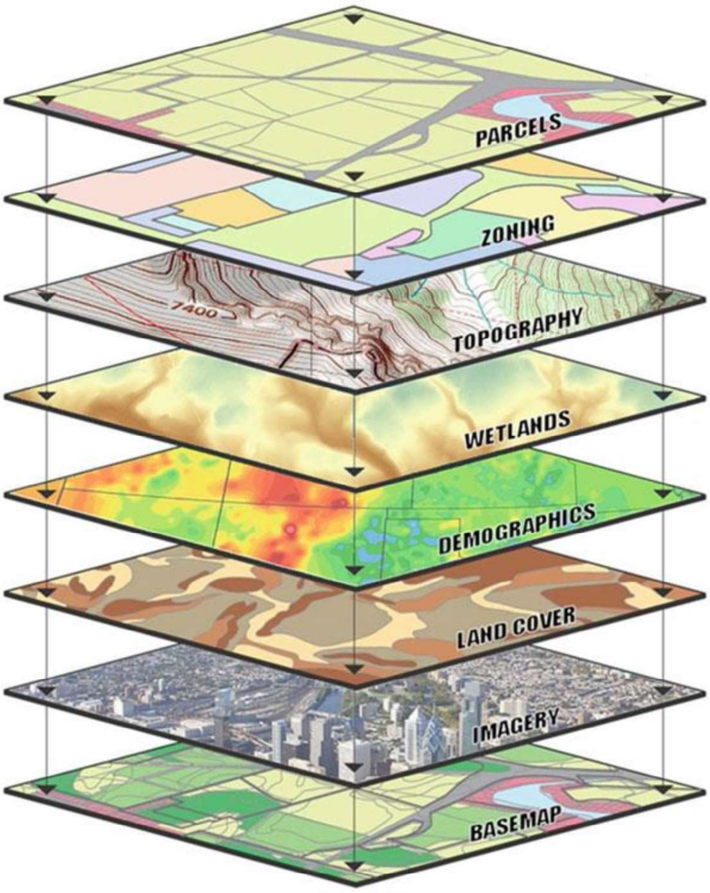


Figure 2.5. Different layers of data can be combined through a GIS to represent realistic and integrated digital maps of the Earth's surface (Source: http://www.turfimage.com/)

These layers of spatial data may be composed by a GIS to enable a more thorough analysis of the geographic data. Layers may also be divided into tiles when they cover a large amount of geographical data. A collection of layers in a database is the spatial component of a geographical database in a GIS. The vector method is related to the object view of organizing geographic information used in cartography, in which geographical objects are identified and are assigned a discrete representation in the data model.

2.3.2 Raster data

Raster data models define the world as a regular set of cells in a grid pattern (Figure 7). These cells are typically square and evenly spaced in the x and y directions. The phenomena or entities of interest are represented by attribute values associated with each cell location. Raster data models are the natural means to represent "continuous" spatial features or phenomena. Elevation, precipitation, slope, and pollutant concentration are examples of continuous spatial variables. These variables characteristically show significant changes in value over broad areas. The gradients can be quite steep (e.g., at cliffs), gentle (long, sloping ridges), or quite variable (rolling hills). Raster data models depict these gradients by changes in the values associated with each cell. Raster data sets have a cell dimension, defining the edge length for each square cell (Figure 2.6). For example, the cell dimension may be specified as a square 30 meters on each side. The cells are usually oriented parallel to the x and y directions, and the coordinates of a corner location are specified (Bolstad, 2016).

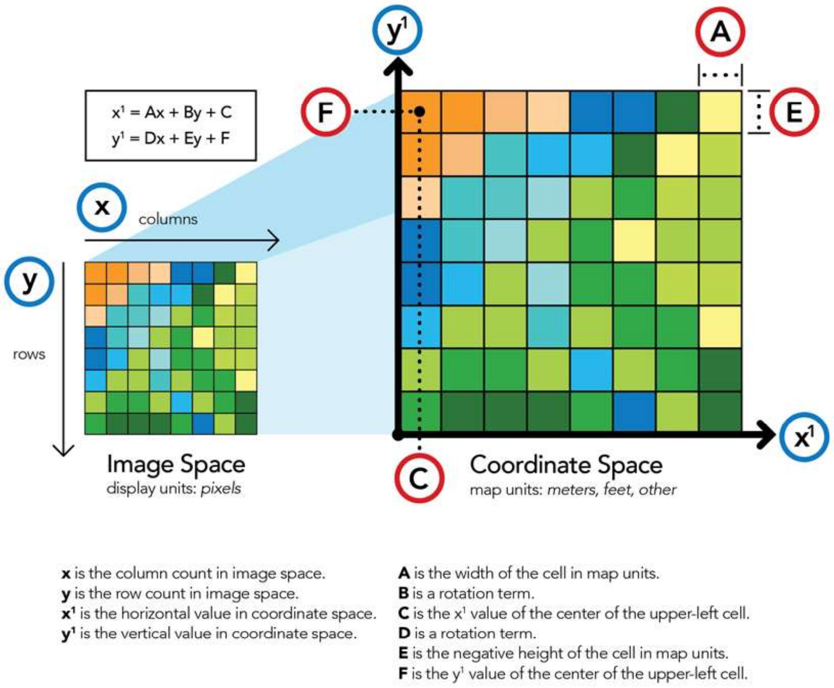


Figure 2.6 Raster data models defined as a regular set of cells in a grid pattern (ESRI: https://www.esri.com/about/newsroom/arcuser/understanding-raster-georeferencing/

In the raster data type, data is represented by pixels with values, creating a grid, allowing certain types of operations that could not be performed with the vector data type (Figure 2.7). Using the raster data type, Map Algebra is used along with multiple data layers to create index maps. The raster data type is useful for storing data that vary continuously, as in the case of aerial photographs, satellite images, surfaces of chemical concentrations, and/or elevation surfaces. Raster data consist of a regular two-dimensional (2D) grid of cells (pixels). The grid is characterized by a georeferenced origin, its georeferenced orientation, and the raster cell size (pixel size). Raster data may also be arranged in three dimensions. In this case, the three-dimensional (3D) cell becomes a cube (a voxel). The geometric accuracy of raster data is limited by the pixel resolution. In raster data, apart from geometric correction procedures, radiometric transformations can be applied. Furthermore, Boolean algebra operators can be used, allowing data combination among different raster layers (Bostland, 2016).

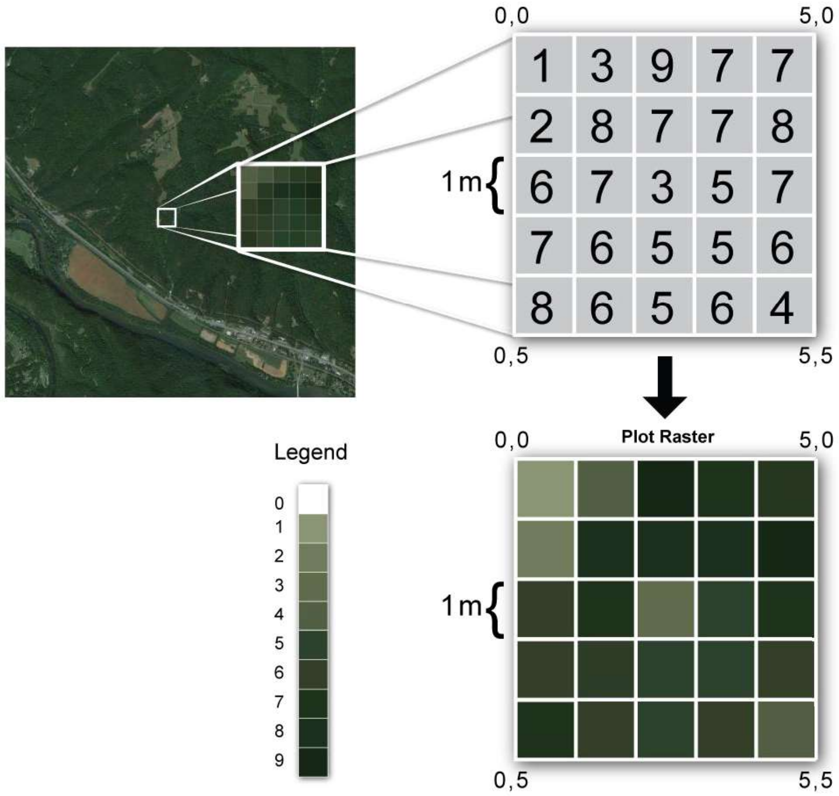


Figure 2.7 Grid (Pixel) in the raster data type

On the other hand, graphical data may come in the form of arrays of pixels owing to the nature of digital imaging instruments (Figure 8). In the raster data model, geographic features are represented by such arrays of pixels, known as raster data. Raster pixels each represent a general characteristic of a geographical feature, and together they compose themes of data. The raster model is based on the field view of data modelling in which geographic features can be represented as regions, surfaces, or segments.

2.3.3 Advantages and disadvantages of vector and raster data

Both vector and raster data have advantages and disadvantages relative to each other and to additional, more complex data models. In some instances, it is preferable to maintain data in a raster model, and in others in a vector model. Most data may be represented in both, and may be converted among data models. The choice often depends on a number of factors, including the predominant type of data (discrete or continuous), the expected types of analyses, available storage, the main sources of input data, and the expertise of the human operators (Table 2.1) (Wade, 2003).

Table 2.1 Characteristics of Raster and Vector data

Characteristic	Raster	Vector
data structure	usually simple	usually complex
storage requirements	arger for most data sets without compression	smaller for most data sets
coordinate conversion	may be slow due to data volumes, and require resampling	simple
analysis	easy for continuous data, simple for many layer combinations	preferred for network analyses, many other spatial operations more complex
spatial precision	floor set by cell size	limited only by positional measurements
accessibility	easy to modify or program, due to simple data structure	often complex
display and output	good for images, but discrete features may show "stairstep" edges	maplike, with continuous curves, poor for images

With the combination of the raster and vector data types, a realistic representation of the world can be achieved (Figure 2.8).

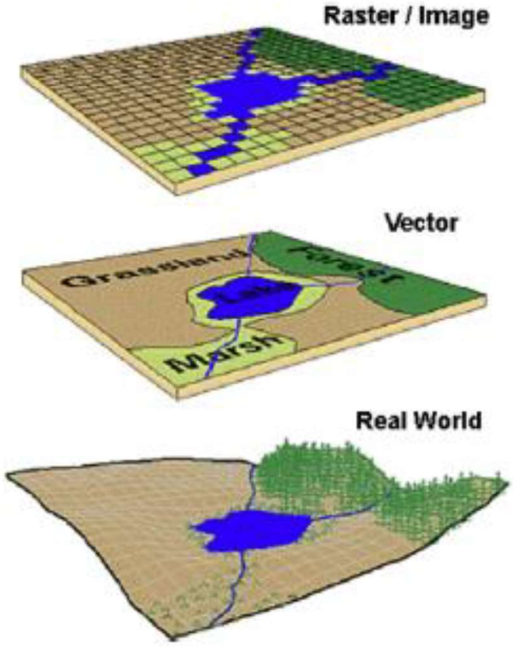


Figure 2.8 Representation of the world with the combination of the raster and vector data types (From http://mwiki.gichd.org:8090/IM/Types_of_Data).

2.3.4 Other Data Models

- *Triangulated Irregular Networks*

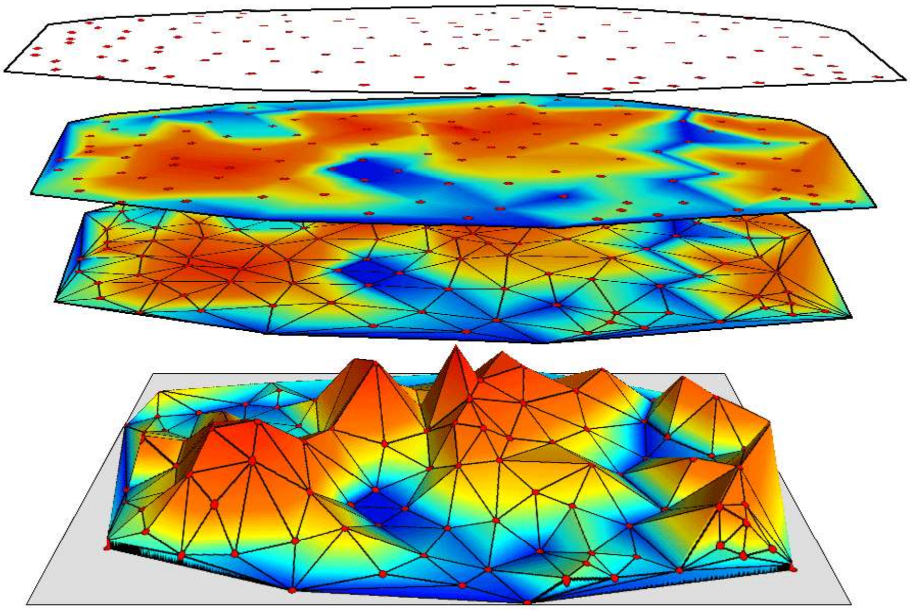
A triangulated irregular network (TIN) is a data model commonly used to represent terrain heights. Typically, the x, y, and z locations for measured points are entered into the TIN data model. These points are distributed in space, and the points may be connected such that the smallest triangle possible spans any three adjacent points. The TIN forms a connected network of triangles (Figure 2.9 a). Delaunay triangles are created such that the lines from one triangle do not cross the lines of another. Each triangle defines a terrain surface, or facet, assumed to be of uniform slope and aspect over the triangle. (Evans, 2001)

- *Object Data Models*

The object data model is an alternative for structuring spatial data. The object data model incorporates much of the philosophy of object-oriented programming into a spatial data model. A main goal is to raise the level of abstraction so that the data objects may be conceptualized and addressed in a more natural way. (Glennon ,2010).

- *Three-Dimensional Data Models*

GIS in built environments is increasingly integrating three-dimensional (3D) (Figure 2.9 b) information such as heights, shapes. Several 3D data models have been proposed, with "vector-like" models more commonly applied than "raster-like" models. (Arras C., 2022)



a

b

Figure 2.9 a) Triangulated irregular network (TIN) (https://www.geosolutions.com/3d/analyse/interpolation.htm); **b)** Three-Dimensional Data Models

2.5 GIS applications in the monitoring of environmental agro-environmental components

1) Environment

GIS has a key role in environmental monitoring, modelling, and assessment, as it offers powerful computer mapping and analyses, capable of integrating large volumes of spatial data as well as linking spatial with nonspatial datasets (e.g., census information, environmental exposure levels). For example, observing environmental changes over time indicates trends and patterns via tools for the display and analysis of time series data. This can be achieved by integrating temporal data within GIS. Also, spatial interpolation methodologies can create continuous surface data layers from sample locations and make predictions. Moreover, GIS is able to represent three-dimensional composites, which are constructed and interactively visualized by creating spatially continuous surfaces or grids, such as geologic structures and/or water-level datasets. (Kolios, 2017). Characteristic examples of environmental issues that are handled through GIS include, among many others:

- Land degradation
- Drought
- Forest fires
- Delineation of protected natural ecosystems
- LULC changes
- Air quality
- Marine pollution

2) Atmosphere, Weather, and Climate

A GIS constitutes a useful tool for scientists and experts in the fields of meteorology, climatology, and atmospheric sciences, helping them to develop more precise weather analysis and numerical model forecasts about weather, climate, and atmospheric composition. GIS can combine different kind of data, such as point measurements from ground stations, satellite imagery, model outputs, radar images, and other scientific instrumentation to provide a realistic approximation of nature and the dynamic evolution of atmospheric motion and physical parameters in time and space (Kolios, 2017). GIS offers a variety of potential benefits regarding the coupling of surface – atmosphere data/models and efficient means to analyse and visualize atmospheric phenomena. By using not only the mapping capabilities but also the spatial analysis tools and methods of GIS software, many applications are possible, such as integration, visualization, forecasting, and support for decision-making regarding potential natural hazards, climate changes, and atmospheric variations (e.g., a GIS is able to calculate weather impacts on Earth using scientific models, vulnerability studies, dispersal of pollutants, impact assessment, etc.) (Kolios, 2017).

3) Agriculture

By mapping geographic and geologic features of current (and potential) farmland, scientists and farmers can collaborate in order to develop and implement more effective and efficient cultivating techniques. Such activities could increase food production and improve food quality. With the use of GIS, soil data can be analysed and combined with well-established farming practices to determine which the best crops to plant are, where they should be cultivated, and how to maintain soil nutrition levels to provide the best possible benefit for the plants. GIS applications focused on agriculture not only can map topography and crop health, but can also help in solving wider socioeconomic issues. GIS capabilities in the agricultural sector can be achieved by integrating high resolution satellite (or aerial) imagery, field observations, and real-time data and by combining them in order to understand how to make the most of limited resources at any time and any place. Another important aspect in this field of application is precision agriculture (PA)—also called precision farming (PF)—which utilizes geographical information to determine field variability and to ensure optimal use of inputs and maximize the output from a farm. Therefore, the combined use of satellite remote sensing, GIS, and GPS can help farmers to more effectively use expensive resources, such as fertilizers, pesticides, and herbicides, and to efficiently use water resources. This modern approach in agriculture not only maximizes the crop yields, but also reduces the operating costs and consequently increases the farmers' profits. (Mani et al. 2018).

2.6 Vegetation mapping and monitoring

The nature and properties of vegetation are fundamental attributes of landscapes. The nature of the vegetation in an area is determined by a complex combination of effects related to climate, soils, history, fire and human influences which can date back several millennia in some locations. When viewed from this historical perspective, vegetation mapping has a long history which includes a variety of contexts and a wide range of geographic scales. From a more modern perspective, one common distinction in vegetation mapping separates attempts to map 'potential' and 'actual' vegetation. Maps of potential vegetation attempt to determine what the vegetation type would be in the absence of human influences (Küchler et al, 1988). Maps of 'actual' vegetation are finalised to characterize the vegetation in that moment. Different vegetation maps emphasize different attributes of the vegetation. Some maps are floristic and are focused on taxonomic differences between places. Others maps are focused on more structural attributes of the vegetation, emphasizing the basic lifeforms of the vegetation and the size and density of cover. The characteristics emphasized in vegetation maps and their scale are typically dependent on the needs and interests of the users of the maps. At one end of the spectrum are global vegetation maps which are often used to study the relationship between vegetation types and climate (Khandare, 2022). More local scales of vegetation maps are often made to serve the needs of local land management. Vegetation can be viewed in a myriad of ways from the land management perspective, including as: a source of food and/or fibre; habitat for wildlife; protection of soils; recreational resources; a regulator of the interactions between the surface and the atmosphere with respect to heat, gases, and moisture; or simply as a fundamental attribute and descriptor of landscapes. Thus, vegetation is fundamental to many environmental processes and as a result it plays a central role for the use of GIS for environmental modelling (Rogan et al., 2002). The first vegetation maps made with the help of remote sensing were based on the visual interpretation of aerial photographs. The basic mapping scenario involves delineation of homogeneous patches, or stands of vegetation, for which labels concerning the properties of the vegetation within the polygon are provided. Typical vegetation properties included are the overall lifeform of the vegetation, dominant species, height and density of the vegetation, and the presence and nature of understory vegetation. Some of these properties are measured using photogrammetric methods, such as vegetation height measurements using a parallax bar (Lillesand and Kiefer 2000). Other vegetation properties are inferred from the tone, colour, shape, texture, pattern, site, context and association observed in the aerial photograph (Estes et al. 1983); they are based on the knowledge of the interpreter and increases with field visits to the area being mapped. Vegetation mapping from satellite images has been dominated by use of data from the reflective wavelengths of the solar spectrum, primarily the visible, near infrared and mid-infrared. The strong reliance of air photo interpretation on the skill and experience of the interpreter is both the strength and weakness of this approach to vegetation mapping. In general, digital analysis of satellite imagery cannot match the quality of vegetation maps derived from outstanding air photo interpretation. Many vegetation maps are still made via air photo interpretation, particularly for areas small enough that the economies of scale associated with digital analysis of satellite imagery are unimportant, or where the requirements for spatial detail or accuracy of the vegetation maps are beyond those achievable with satellite remote sensing. Vegetation mapping was one of the first uses of satellite remote sensing imagery and has been one of the most common ever since (Xie et al., 2008).

2.7 Multispectral data and image classification

The first and most common approach used for map vegetation from satellite images is the use of multispectral data in image classification. In this approach patterns of spectral reflectance, or 'spectral signatures', are associated with different vegetation types. In the image classification step, each pixel in the image data is assigned to a particular vegetation type, resulting in a map. This paradigm has used data primarily from the solar reflective wavelengths, but other kinds of data were later included, such as texture data or other kinds of map data such as topographic variables. The supervised classification approaches require training sites as input prior to the image classification step which are used to characterize the spectral signatures of the vegetation types. Initially, parametric statistical classifiers such as maximum likelihood dominated (Skidmore, 2017). Unsupervised classification proceeds by allowing the computer to define spectral clusters of pixels, or groups of pixels in the image with similar spectral properties. Each pixel is then assigned to one such cluster. User input is necessary to associate vegetation types with spectral clusters. Many factors influence the reflectance from vegetation canopies, some diagnostic of the vegetation types of interest in the mapping process and others unrelated. The vegetation factors known to influence the spectral reflectance of vegetation canopies include the overall life form of the vegetation, leaf properties (leaf area and leaf angle distribution and spectral reflectance properties), vegetation height or tree size, the fractional cover of vegetation, and the health and water content of leaves. In addition, the soil colour and wetness contribute to the spectral response at any given location in the image. The net effect is that the same vegetation type may have many spectral manifestations in the image, which significantly complicates the image classification process. One issue that compare the use of digital satellite images for mapping vegetation concerns the scale, or the relationship between the size of individual pixels and the desired scale of the resulting map. Several approaches exist for this situation, including: filtering of the images resulting from per-pixel classifiers (Lavreniuk, 2018); spatial or contextual information in the classification process (Sanlang, 2021), and the segmentation of images into polygons in a step independent of image classification (Novotný, 2021). The relationship between vegetation mapping and GIs is mutually beneficial. On one hand, vegetation maps are used extensively within GIs for the purposes of environmental modelling. However, the integration of other kinds of map data with remote sensing images through the use of GIs has greatly improved the vegetation mapping process. It is this dimension of the relationship between vegetation mapping and GIs which is emphasized in this Vegetation mapping, based solely on image classification of multispectral data is limited with respect to the vegetation attributes that can be provided in a reliable manner. In this case it is particularly evident the difficulty of mapping vegetation at the level of detail of individual plant species. The use of topographic data to improve or increase maps made using satellite images data represent one of the earliest attempts to use satellite remote sensing to make vegetation maps (Mather, 2016). The primary intent of the use of topographic data was to capture the influence of climate on species distributions, with topographic variables of elevation, aspect and slope being used as surrogates for temperature and moisture conditions. Such approaches have been proven highly successful and are used frequently in vegetation mapping efforts (Novotný, 2021). A number of response models have been developed to investigate the relationships between different environmental factors and the distribution of forest species (Guisian, and Zimmermann, 2000). These models have included environmental variables such as nutrient availability, rainfall, temperature (Guisian and Zimmermann, 2000), topographic position (Austinet et al., 1994), elevation, aspect, exposure to wind, slope position (MacMillan et al., 2004), soil structure and soil nutrients (AbdelRahman et al., 2021). Some of these models have used a solar radiation index for vegetation mapping, reporting a strong correlation between solar radiation and the distribution of several species along a single transect. These models have calculated solar radiation over individual field plots through field measured parameters using the method (Skidmore, 2017) or have used radiation measuring devices, such as pyranometers.

Previous research showed that the distribution of vegetation responds directly to environmental factors including temperature, moisture regime and nutrient availability; since temperature and moisture regime may be linked to solar radiation (Santamouris, 2013), it is hypothesized that the distribution of vegetation should be related to solar radiation. Two additional kinds of information which have been used in vegetation mapping based on satellite images are spatial and temporal patterns. The use of spatial patterns, or texture, is based on the long-recognized value of texture in air photo interpretation for differentiating vegetation types. To use texture in vegetation mapping using satellite imagery, a new texture band is created from one of the original spectral bands. The texture band (or bands) are then combined with the original spectral bands in the image classification process, increasing the number of input bands. It represents an attempt to exploit in automated image classification one kind of information which contributes greatly to visual interpretation of air photos. Several studies have shown the use of texture data to improve vegetation maps derived from satellite imagery (Skidmore, 2017). Temporal patterns, or the change in reflectance properties over time, have been used extensively for mapping vegetation at continental to global. Recently, several investigators have found that use of multitemporal images can improve vegetation mapping at local to regional scales using images such as Landsat TM or SENTINEL (Fassnacht et al., 2016). Vegetation health, condition and change through time are of great interest from a variety of perspectives. Satellite images, primarily due to its synoptic views of landscapes and multitemporal sensing, is well suited for monitoring vegetation health. It has sometimes been successful the use of single satellite images to map the positions of the vegetation affected by various environmental factors and the exploitation of plant resources such as pastoralism and breeding in the wild; it is much more common to use the multitemporal satellite images to monitor the health of vegetation. In this approach, images from different periods for the same position are co-registered in such a way that the spectral values of the two moments can be compared directly. In several settings, multi-data image analysis has proved effective for monitoring of forest defoliation due to insects (Huang, 2021). Vegetation is a fundamental attribute of landscapes which influences a whole host of environmental processes. Mapping of vegetation via remote sensing is providing information on vegetation properties for large parts of the world in sufficient spatial detail to aid environmental modelling. Vegetation mapping at local to regional scales is currently dominated by images from the Landsat and SeNTINEL satellites, but future vegetation mapping will be improved by use of hyperspectral images, radar images, and high spatial resolution images. Monitoring of vegetation change using remote sensing is providing an improved understanding of the health and condition of vegetation as well as rates of conversion of natural vegetation to other land uses.

2.7.1 Spectral Information

There is a variety of new types of images used for the mapping of vegetation and other environmental components. They have great potential to improve types of information that can be provided in the future on vegetation through remote sensing. The interpretation of spectral information is at the very core of remote sensing data analysis. The spectral signal carries much more information about the land surface than what it is immediately visible to the human eye. Physical states such as photosynthetic activity, water stress, leaf biochemical constituents, all contribute to shape the reflected spectral signal (Figure 10). To harness this wealth of information in a normalized way, the originai bands are often transformed into new synthetic bands, so-called spectral indices, by using mathematical operntions.

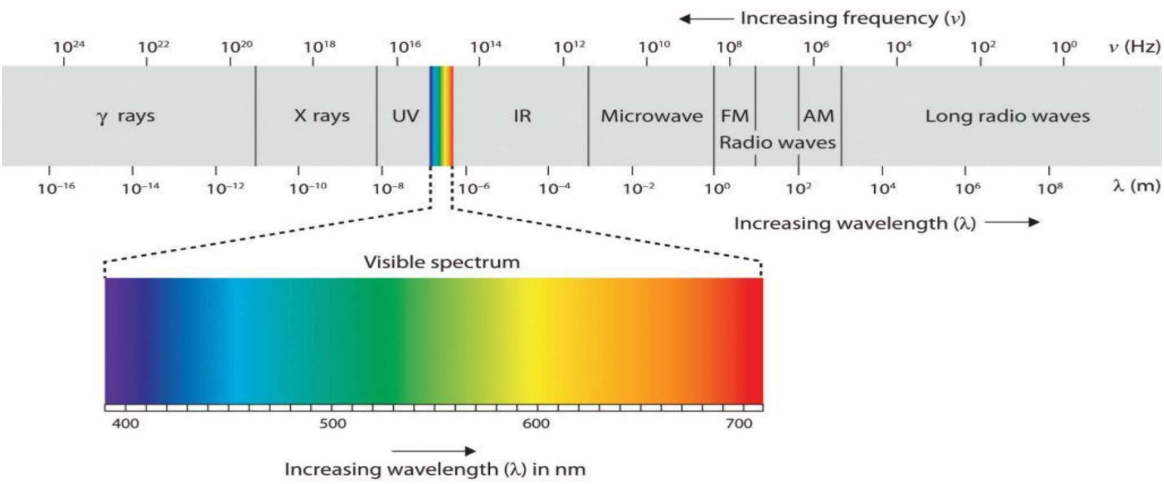


Figure 2.10 Reflected spectral signal

A considerable number of spectral indices targeting different biophysical properties have been developed in the past. Vegetation indices are often used as physically interpretable predictors in land cover change analysis, species distribution modelling or the spatial resource use of animals. The use of spectral indices has several advantages over the use of original reflectance. First, they can dramatically enhance the identification of certain specific land cover types in visual or automated image interpretation, for example, vegetation *vs* open soil. Second, many indices involve the mathematical division of bands, which has a normalizing effect on illumination variability within a single scene and also between scenes. This can reduce terrain or cloud-induced illumination effects, improve multitemporal comparability in a time series and may even reduce the need for precise atmospheric correction. Third, spectral indices are usually geared towards describing actual physical measures of the land surface, such as the degree of vegetation cover or water stress within vegetation. These are measures that allow interpretation in an ecological context (Wegmann et al., 2016).

2.8 Use of GIS in support to species biology and faunistic management

Wildlife management requires reliable and consistent information on the abundance, distribution of species and their habitats as well as threats. The main purpose of wildlife conservation is to maintain maximum plant and animal diversity through genetic traits, ecological functions and bio-geo-chemical cycles, as well as maintaining aesthetic values (IUCN 2021). This has been achieved to a certain extent through the creation of parks and reserves in different parts of the world. These areas are set aside and managed to protect individual plant and animal species, or more commonly of assemblages of species, of habitats and groups of habitats. Different criteria are used in the establishment of parks and nature reserves. Ideally, they should include communities of plants and animals that are in balance, and exhibit maximum diversity (Alemu et al., 2016). However, some areas have been designated as parks or reserves based on high-profile species only or because they form a habitat for endangered or endemic plants or animals or are unique natural landscapes. Many parks are declared for purposes other than wildlife conservation. For over a century national parks and reserves have been the dominant method of wildlife conservation (Alemu et al, 2016). Many of these areas are not complete ecological units or functional ecosystems in themselves, consequently they have determined a range of management problems. The main problem is the general decline in plant and animal diversity. A new approach is thus the 'ecosystem approach' to promote biological diversity outside the traditional protected areas (Smith, 2003). Wildlife, and its conservation, is in crisis. Unprecedented and increasing loss of native species and their habitats has been caused by different human activities. Management strategies have focused mainly on single species and protected areas. Immediate conservation is required particularly for areas outside the protected area system, which have rich wildlife resources. However, this action is hampered by lack of information and knowledge about species abundance, species distributions and factors influencing their distributions in these areas. Also, there is general lack of understanding about the ecological, social and cultural processes that maintain diversity in different areas or ecosystems, i.e., of wildlife conservation at a landscape scale (Prip, 2018).

2.9 Wildlife conservation and reserve management

With the exponential growth of human populations, and the consequent demand on natural resources, the Earth is being transformed from large expanses of natural vegetation towards a patchwork of natural, modified and man-made ecosystems. Faced with this reduction, fragmentation or complete disappearance of their specific habitat, many wildlife species have suffered reductions in their numbers or range, or have become extinct. The underlying factors responsible may be classified as those with a direct negative effect, such as hunting, fishing, collection or poaching, and those indirectly detrimental to wildlife through impact on their habitat. Among these, the alteration and loss of habitat is considered the greatest threat to the richness of life on Earth (Groom et al., 2016). Over the last century, conservation efforts have concentrated on the acquisition and subsequent protection of critical wildlife habitat. Many of these parks and reserves, however, were created as attractions with geological or aesthetic appeal rather than for biological conservation. In general, they are remnants of lands with marginal agricultural value, while highly productive lands tend to be underrepresented (Groom et al, 2016). The International Union for Conservation of Nature (IUCN) recommend the preservation of a cross-section of all major ecosystems and called for protection of 13 million km2 of the Earth's surface. Once established, reserves do not necessarily guarantee the conservation of wildlife, because various processes operating within their boundaries might negatively affect wildlife. In many cases, protection within reserve remains marginal at best, exposing wildlife to incompatible land uses such as livestock or over exploitation. In addition, exotic diseases or invasive species may impact wildlife populations (Davies et al, 2012). Modification of the environmental conditions including the availability of resources such as water points for livestock, may change the balance amongst native species, advantaging some and disadvantaging others. Visitors may exert a negative impact on wildlife or their environment, particularly in highly frequented areas or where sensitive species occur. Traditionally, wildlife management is focused on the maintenance of some desired state of the resources within the reserve, while controlling factors negatively impacted on wildlife and the resource base on which they depend. Such internal management does however not guarantee sustainable wildlife conservation. Biological and physical processes in the surrounding areas may negatively impact on populations residing in the reserve (Davies et al., 2012). Fragmentation of wildlife habitat outside reserves is considered a potentially important factor that affect negatively wildlife (Joenes et al., 2021). Wildlife populations in reserves might be too small to persist on their own and depend on their long-term survival on interbreeding with other sub-populations inhabiting similar habitat outside. Fragmentation of the habitat outside would increase the isolation of the population inside the reserve and increase the probability of extinction (Jones et al., 2021). Nowadays many reserves are characterised by an increased intensity of land use at their periphery. Therefore, successful wildlife management requires the provision and maintenance of optimal conditions both within and outside reserve boundaries. Species with large territories may be at risk when individuals cross reserve boundaries, e.g. Brown Bear (*Ursus arctos marsicanus*) may be shot by rangers when posing a threat to cattle. Successful wildlife management requires appropriate data on wildlife especially data on spatial and temporal abundance and distribution. Remote sensing and GIs techniques are increasingly being used in the collection and analysis of these data as well as the monitoring and overall management of wildlife.

2.10 Mapping wildlife distribution

Geographic information on the distribution of wildlife populations forms a basic source of information in wildlife management. Most commonly, distribution is derived from observations in the field of the animal species or their artefacts. Radio-telemetry and satellite tracking have been used to record the distribution of a variety of animal species. Satellite remote sensing undoubtedly has a potential for mapping of animal distribution, but successful applications seem to be few (Millspaugh, J, 2001).

2.11 Mapping wildlife resource requirements

Resources used by animals include those material required to fulfil their life cycle such as food, drinking water, nesting sites, shelter etc. Vegetation maps tend to be used to map the spatial distribution of these resources. In some studies, the distribution of a species has been related directly to the classes or map units of these vegetation maps (He et al., 2019). It remains undetermined whether the animal is located in one vegetation class or another because of the availability of food resources, shelter, nesting or a combination of those. Typically, vegetation maps contain thematic information on physiognomy, species composition or some other vegetation attributes. Wildlife managers prefer information on the amount of 2nd quality food resources, which are considered major factors determining the distribution of animals. Remote sensing has been applied to quantify the spatial distribution of vegetation biomass (Hame et al., 1997). This quantification is mainly made by means of Normalized Difference Vegetation Index (NDVI), or 'greenness index'. Annually, integrated NDVI was shown to be related to biome averages of annual net primary production (NPP). Prince (1991) demonstrated that there is a strong linear relationship between the satellite observation of vegetation indices and the seasonal primary production and determined the relationship between time-integrated normalized difference vegetation index statistics and total herbaceous biomass through regression analysis. He concluded that availability of several years of data makes it possible to identify the temporal and spatial dynamics of vegetation patterns within the Sahel of Niger in response to year-to-year climatic variations. Although the NDVI appears to be a useful index of some surface phenomena many studies have been undertaken to relate NDVI to crop production or grass biomass production (de Leeuw et al., 2002). Drinking water constitutes a critical resource to wildlife, particularly in arid and semi-arid zones. Hence, one would expect water dependent animals to be close to watering points.

2.12 Mapping and modelling habitat suitability for wildlife

Habitat Suitability Models (HSMs) are empirical methods that relate species' field observations or museum- type species data to environmental predictor variables, based on a combination of statistically or theoretically derived response curves, that best reflect the ensemble of ecological requirements of the species. HSMs are models of the relationship between presence and the abundance of a species and the characteristics of the habitat in which it lives (Morrison et al., 1992). They are aimed at identifying in a territory those areas which, thanks to their environmental characteristics, are suitable for hosting a certain species. The important environmental parameters are many and vary according to the species. They concern all those morphological, vegetational, climatic factors, trophic, anthropic, which determine, or influence, the availability of food and shelter, the ability to reproduce, the quality of the environment, the interaction with other species, the man-made disorder. Fundamental elements of any valuation model faunistic are, in addition to the environmental variables, the indicators and the function of classification (Pedrotti and Preatoni, 1995).

Some possible uses and applications of HSMs are:

1. Quantifying the environmental niche of species and its changes in time and space

2. Evaluating the environmental drivers determining species ranges

3. Relating HSMs to species characteristics or population demography

4. Testing evolutionary hypotheses in biogeography

5. Assessing species invasion and proliferation

6. Assessing the impact of climate, land use and other environmental changes on species distributions

7. Suggesting unsurveyed sites with a high potential of occurrence for rare or new species

8. Supporting appropriate management plans for species recovery and mapping suitable sites for species restoration

9. Supporting conservation planning and reserve selection

10. Modelling community and ecosystem properties from individual species predictions

11. Detecting and anticipating disease spread and outbreaks

12. Incorporating habitat suitability into landscape meta-population dynamic assessments

HSMs can be classified according to two main criteria (Ranci Ortigosa, 1997). The first criterion is based on the source of the data that constitute the experimental basis of the template. Basic data are subjective if they are taken from the literature or comes from the author's experience; they are instead objective if they have been measured on the field. The second criterion, on the other hand, is based on the method followed for the determination of the classification function. It is said to be implicit if it is the result of subjective considerations not mathematically formalized and which translate opinions of experts, explicit if in its formulation extensive use of methods was made mathematical and statistical, univariate and multivariate. (Table 2.2).

	Basic data	
Variable relationship - indicators	subjectivity *(experience + bibliography)*	objectivity *(misurered in the field)*
Implicit (*descriptive*)	QUALITATIVE	ALMOST QUALITATIVE
Explicit (*use of mathematical and statistical methods*)	ALMOST QUANTITATIVE	QUANTITATIVE

Table 2.2 Classification of environmental evaluation models (Morrison et al. 1992).

The characteristic of the HSMs is the expression of the aptitude of an area to host a certain one species as a function (typically the geometric mean, the arithmetic means or a combination of the two) of the suitability indices of the individual parameters environmental. These indexes associate to all the values that each single variable can assume a score, often between 0 and 1, expressive of the goodness of that value for the presence of the species considered. For each model it is defined the applicability, specifying the geographical area and the season for which it was developed. HSIs are useful for representing in a simple and easy form the relationship between a habitat and the species that lives in it is understandable. Their importance consists in providing, as a final result, an index that can be calculated in different situations and compared to evaluate alternative projects (Ranci, 2000).

2.13 Modelling Species-Environment relationships

The ability to model spatial distribution and change in distribution of wildlife is of considerable importance in wildlife management. Once spatial distribution can be adequately modelled, distribution and abundance may be monitored effectively over time. GIS can be effective in modelling animal distribution if the necessary data are available. However, data availability is currently the limiting factor in many areas. Production of a suitability map requires a model to predict the suitability of land for a wildlife species given both a set of land attributes and also distribution of potential competitors. Habitat suitability index (HSI) models, described by Atkinson (Corsi et al., 2000) as hypotheses about species-environment relationships based on the literature and opinions of experts, are an example of theoretical-deductive wildlife-environment relationship models. Deductive modelling, however, has severe drawbacks in wildlife ecology. For many species, the knowledge about habitat requirements simply does not exist. However, expertise with respect to wildlife habitat requirements may be limited, biased or not be available (Kangas et al., 1993). Inductive modelling has been suggested to overcome these problems. Inductive modelling is based on the analysis of data resulting in the generation of new knowledge and the formulation of new models. Here modelling goes from the specific case (field data) towards a generalization. A variety of analytical techniques has been used to investigate species environment relationships. These include logistic regression, discriminant analysis, classification and regression trees, canonical correlation analysis, supervised non-parametric classifiers and neural networks (Schluter,2010).

2.14 Satellite Remote Sensing to identify, mapping and monitoring wildlife corridors

The potential for the use of RS and GIs technologies in wildlife mapping, natural resource planning and management are large. Habitat loss and fragmentation is a major threat to biological diversity, as it can lead to isolated, small populations of wildlife becoming more common. Increases in the number of these small and isolated populations are of high concern for conservation biologists because these populations are known to have higher extinction rates (Hilty et al., 2019). One of the possible strategies to increase the effective size of these populations, making them more resilient to inbreeding, demographic stochasticity and the effect, is to include corridors in conservation plans so that connectivity between otherwise isolated patches of habitat is increased. Corridors in this context are defined as strips of native vegetation or habitat connecting otherwise isolated remnants. They are thought to facilitate movement between connected patches of habitat, and thus increase gene flow, promote the re-establishment of locally extinct populations and increase species diversity within otherwise isolated areas (Rudnick, 2012). Satellite remote sensing can be a valuable tool for identifying and monitoring corridors, for various species and in various environmental contexts. The environmental and anthropogenic factors directly and indirectly are in relation to the transit corridors of animal species (Porter, 2021). (Figure 2.11)

Figure 2.11 Example of ecological network mapping (http://ubigreen.fondazionecariplo.it/)

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EXPERIMENTAL APPLICATIONS

PART I

Assessing the risk of damages by wild boars (*Sus scrofa*) in Italian landscapes and relation to the incidence of road accidents: the case of Molise Region

Submitted to the journal: LANDSCAPE ONLINE

ABSTRACT

Wildlife, and in particular wild ungulates, have undergone a strong demographic increase throughout Europe, especially in the last thirty years. The most widespread ungulates in the Molise region are the wild boar (*Sus scrofa* L.). The aim of this study was to create a first potential impact map of wild boars in Molise region, in accordance with the ISPRA protocols and in relation to the incidence of road accidents. It was processed a map through a GIS software. The impact of the wild boar was referred to the different land use category. Geo-referenced data concerning the road accidents in Molise Region were collected. It was carried out an analysis of the environmental characteristics of the neighbouring raster considering the presence of roads especially with accidents events. The geo-referenced damages were overlaid with the impact risk map. The geo-referenced damages of wild boars demonstrate how almost all the damages are concentrated in the areas where road accidents have occurred and where there is the maximum risk of impact. These maps represent a good starting point for the management of the territories, in order to develop the best strategy from a technical and economical point of view.

KEYWORDS: Human-wildlife conflict, Landscape features, Wild boars (Sus scrofa), Spatial data, Road accidents.

1. INTRODUCTION

Wildlife, and in particular wild ungulates, have undergone a strong demographic increase throughout Europe, especially in the last thirty years (Tack, 2018). Wild boars (Sus scrofa) are widely distributed in several European areas. This species is considered invasive and damaging to agriculture and environment (Sáez-Royuela and Tellería 1986; Bieber and Ruf 2005). The wild boar has been listed in the 100 "World's Worst Invaders" by the IUCN's group of invasive species specialists (IUCN, 2019). In the Molise Region the presence of these ungulates is particularly high (Coldiretti, 2021). This is mainly due to: the abandonment of the countryside and in particular of Apennines areas; the strong reforestation habitat; the climate change and the considerable food availability; the increase of areas off-limits to hunting activity linked to the rise of protected areas (Parks and Protected Areas, Oases, Restocking and Capture wildlife Areas, Dog Training Areas, etc.) (Riga et al., 2011). The most widespread ungulates in the Molise region are the wild boar (*Sus scrofa L.*) and the roe deer (*Capreolus capreolus L.*) (Regione Molise, 2016, 2017). The considerable diffusion of these ungulates has led to an increase in social and economic advantages and benefits, such as the possible use for tourist-hunting activities, but it has also caused an increase of the human-wildlife conflict in anthropized areas (Riga et al., 2011.). However, through the use of Geographic Information System (GIS) software, it is possible to plan some management strategies that can reduce the impact of these species on the territory and stimulate a balance between environment and human activities. In 2013 the ISPRA (Italian Institute for environment protection and research) published the guidelines for the management of ungulates (Raganella Pelliccioni et al., 2013). These guidelines concern the strategy for a correct territorial management mainly referred to wild ungulates through the use of information technology tools (GIS) and the development of repeatable techniques. The aim of this study was to create a first potential impact map of ungulates in Molise region, in accordance with the ISPRA protocols (Monaco et al., 2003; Monaco et al., 2010). Significant areas were identified in relation to the control interventions for the containment of species against agricultural crops and anthropized areas (art. 19 L.N. 157/92) and in relation to the incidence of road accidents caused by wild ungulates (Giugni A. et al. 2016).

2. MATERIAL AND METHODS

a. Study Area

The study area is the Molise Region located in the central southern part of the Italian Apennines, on a territory of 4,438 sq km, and represents the smallest region in Italy, after the Aosta Valley. The territory is predominantly mountainous (55.3% of the total surface), while the hilly areas represent 44.7% of the total. The wooded areas are concentrated in the mountainous and high hilly territories characterized by a considerable abandonment of crops and landscapes. In these territories the urbanized areas are very low (1.2% of the regional surface); the agricultural areas represent 58.7% and the woods occupy 27.3% of the regional surface. In these landscapes there are also grasslands and pastures (8.7%), scrubs (3.3%), barren lands (0.4%) and water bodies (0.3%). The wooded Molise area covers a total of 145.3 thousand hectares (second National Forest and Carbon Inventory - IFNC), and represent 32.8% of the total area of Molise Region. The wooded Molise area constitutes about 1.4% of the total Italian wooded area. Of these, 144.5 thousand hectares are attributable to the class of

"Woods and other wooded lands” (99.4% of the total), while the wood arboriculture systems extend over approximately 800 hectares (Table 1)(Regione Molise, 2014).

Table 1: Altitude range and land use in Molise Region (Regione Molise,2014)

Altitude range	Sq Km	% Regional surface
Lowland	0	0
Hill	1.984	44,7
Mountain	2.454	55,3
Total	4.438	100
Land use	ha	% Regional surface
Urban areas	5.393,40	1,2
Agricultural areas	260.615,80	58,7
Grasslands and pastures	38.760,20	8,7
Scrubs	121.055,50	27,3
Barren lands	1.755,10	0,4
Water bodies	1.179,20	0,3
Total	443.613,80	100

b. Data

The map processing was realized through a GIS software (QGis 3.16 Hannover, distributed under the GNU license - General Public License). The GIS software includes a set of software tools for acquiring, storing, extracting, transforming and visualizing spatial data from the real world (Burrough, 1986). It is based on a spatial DBMS (Data Base Management System) able to manage the positions of the elements on the territory and link to geographic information as well as with textual and numerical information. Data were processed using the cartographic system Copernicus (Copernicus, 2014). The Copernicus cartographic system is the European Union's Earth observation programme, looking at our planet and its environment to benefit all European citizens. It offers information services that draw from satellite Earth Observation and in-situ (non-space) data, (https://land.copernicus.eu). The vector geographic open data CLC 2018 version is v.2020_20u1 were downloaded; it contains the use and land cover created by analysing the aerial photos collected in 2017. This file is the most updated, as the Molise Region does not have a cartographic portal; it is in polygonal vector format, shape file version. The vector file contains several fields (fields); the field that describes the values of the 44 land use categories is Level III - 2018 Corine Land Use (Figure 1).

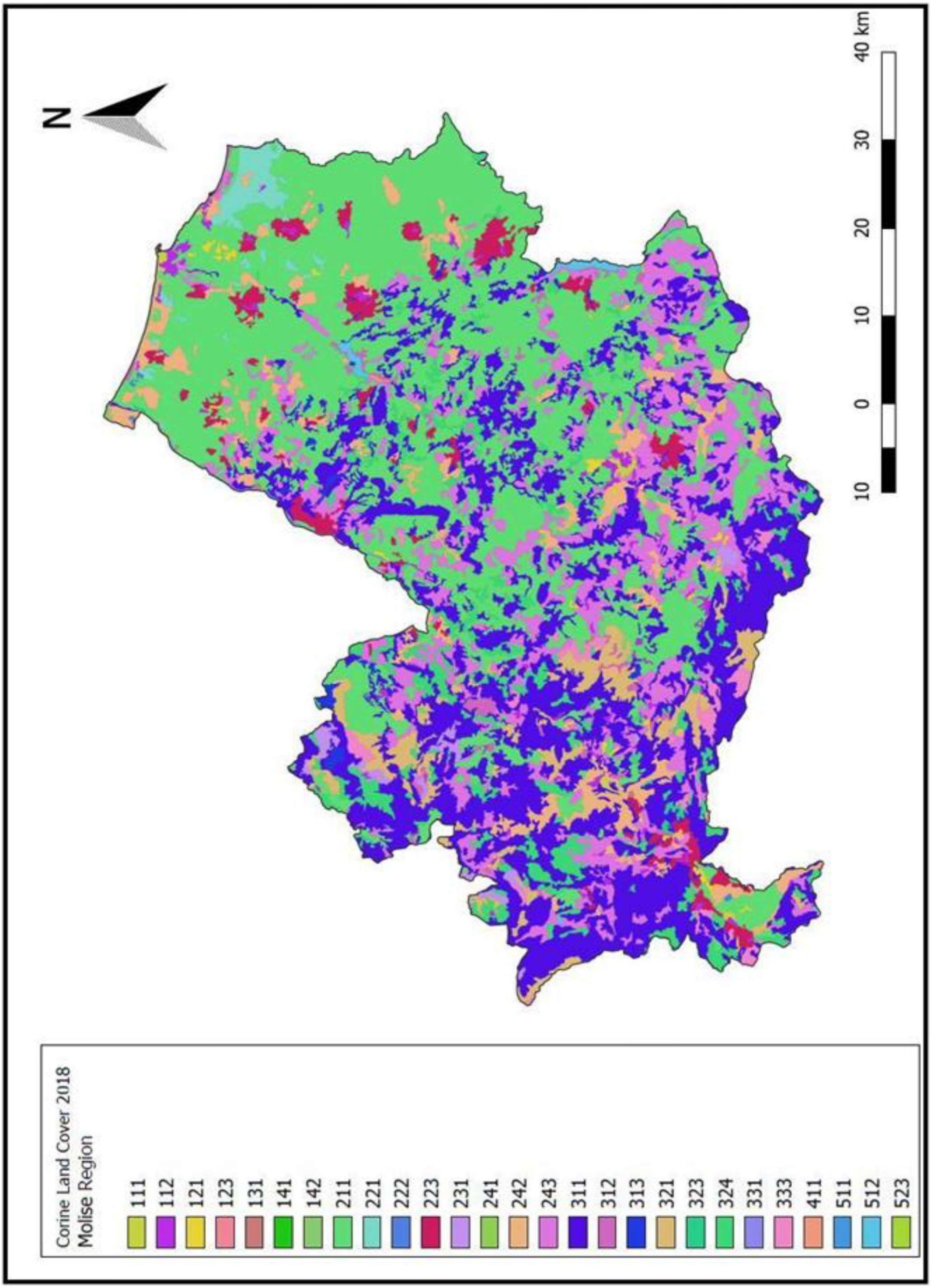

Figure 1: Corine Land Cover Molise Region 2018 – Level III (Bossard et al., 2000)

Table 2: Corine land cover legend in Molise Region (Bossard et al., 2000)

CORINE LAND COVER LEGEND				
Level 1	Level 2	Level 3	Grid_Code	Impact_Wb
1. ARTIFICIAL SURFACES	1.1Urban fabric	1.1.1 Continuous urban fabric	1	5
		1.1.2 Discontinuous urban fabric	2	5
	1.2 Industrial, commercial and transport units	1.2.1 Industrial or commercial units	3	5
		1.2.2 Road and rail networks and associated land	4	5
		1.2.3 Port areas	5	5
		1.2.4 Airports	6	5
	1.3 Mine, dump and construction sites	1.3.1 Mineral extraction sites	7	5
		1.3.2 Dump sites	8	5
		1.3.3 Construction sites	9	5
	1.4 Artificial, non-agricultural vegetated areas	1.4.1 Green urban areas	10	5
		1.4.2 Sport and leisure facilities	11	5
2. AGRICULTURAL AREAS	2.1 Arable land	2.1.1 Non-irrigated arable land	12	5
		2.1.2 Permanently irrigated land	13	4
		2.1.3 Rice fields	14	4
	2.2 Permanent crops	2.2.1 Vineyards	15	4
		2.2.2 Fruit trees and berry plantations	16	4
		2.2.3 Olive groves	17	2
	2.3 Pastures	2.3.1 Pastures	18	2
	2.4 Heterogeneous agricultural areas	2.4.1 Annual crops associated with permanent crops	19	2
		2.4.2 Complex cultivation patterns	20	4
		2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation	21	4
		2.4.4 Agro-forestry areas	22	1
3. FOREST AND SEMI NATURAL AREAS	3.1Forests	3.1.1 Broad-leaved forest	23	0
		3.1.2 Coniferous forest	24	0
		3.1.3 Mixed forest	25	0
	3.2 Scrub and/or herbaceous vegetation associations	3.2.1 Natural grasslands	26	2
		3.2.2 Moors and heathland	27	0
		3.2.3 Sclerophyllous vegetation	28	0
		3.2.4 Transitional woodland-shrub	29	0
	3.3 Open spaces with little or no vegetation	3.3.1 Beaches, dunes, sands	30	3
		3.3.2 Bare rocks	31	0
		3.3.3 Sparsely vegetated areas	32	0
		3.3.4 Burnt areas	33	0
		3.3.5 Glaciers and perpetual snow	34	0
4. WETLANDS	4.1 Inland wetlands	4.1.1 Inland marshes	35	3
		4.1.2 Peat bogs	36	3
	4.2 Maritime wetlands	4.2.1 Salt marshes	37	3
		4.2.2 Salines	38	5
		4.2.3 Intertidal flats	39	3
5. WATER BODIES	5.1 Inland waters	5.1.1 Water courses	40	0
		5.1.2 Water bodies	41	0
	5.2 Marine waters	5.2.1 Coastal lagoons	42	0
		5.2.2 Estuaries	43	0
		5.2.3 Sea and ocean	44	0

The polygonal vector file with the administrative boundaries of the municipalities of the Molise region was downloaded from the portal of the National Statistical Institute (ISTAT, 2021); a new file was then created according to the Regional Law 10 August 1993, n ° 19 - Molise Region (Regione Molise, 1993). Table 2 shows the Impact table in Molise Region: a column shows the impact of the wild boar species referred to the different land use category. For each land use category, values ranging from 0 (zero impact) to 5 (certain impact) have been assigned. The impact values were divided into the following categories:

• 5: urban and similar areas (certain impact)

• 4: valuable cultivated areas (very small impact)

• 3: cultivated areas (open) where impact is possible

• 2: cultivated areas where the impact is low

• 1: not significant impact

• 0: null impact

The first processing to define potential impact maps concerned geoprocessing operations. In particular with the join field function the Impact Table includes the potential impact values that were linked to each polygonal vector file of land use. As a result, a polygonal vector file was produced for each area similar to the polygonal vector file of the Corine land Cover, with 5 additional fields coming from the table (5 certain impact, 0 zero impact) and connected to the target of wild boars species studies (Figure 2). By acting on the symbology it is possible, using the classification of impact in the fields, to easily observe the potential impact of the wild boar at the regional level. Subsequently, a file in raster format was created by using the convert polygon to raster function, which facilitated analysis and reading (Figure 3). These raster files have cells of 10 m x 10 m, containing the potential impact values of the vector polygonal file referred to each single cell. Analysing the map of the Molise Region, the potential impact of the most significant wild boar in urban areas (Molise Centre around the city of Campobasso) and in the agricultural areas of the Lower Molise lowland and coastal area (east) is evident.

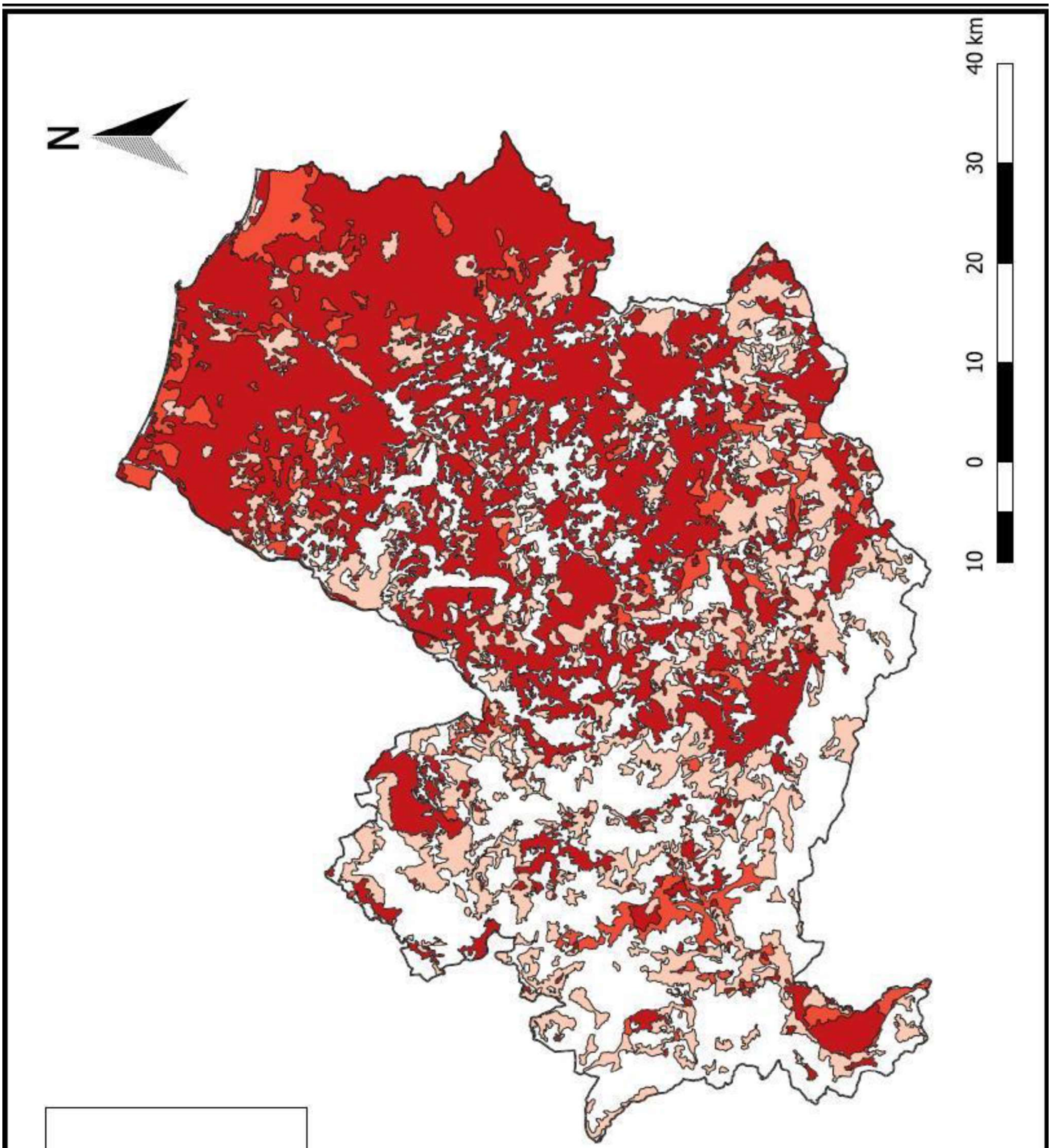

Figure 1: Vector impact map of Molise Region

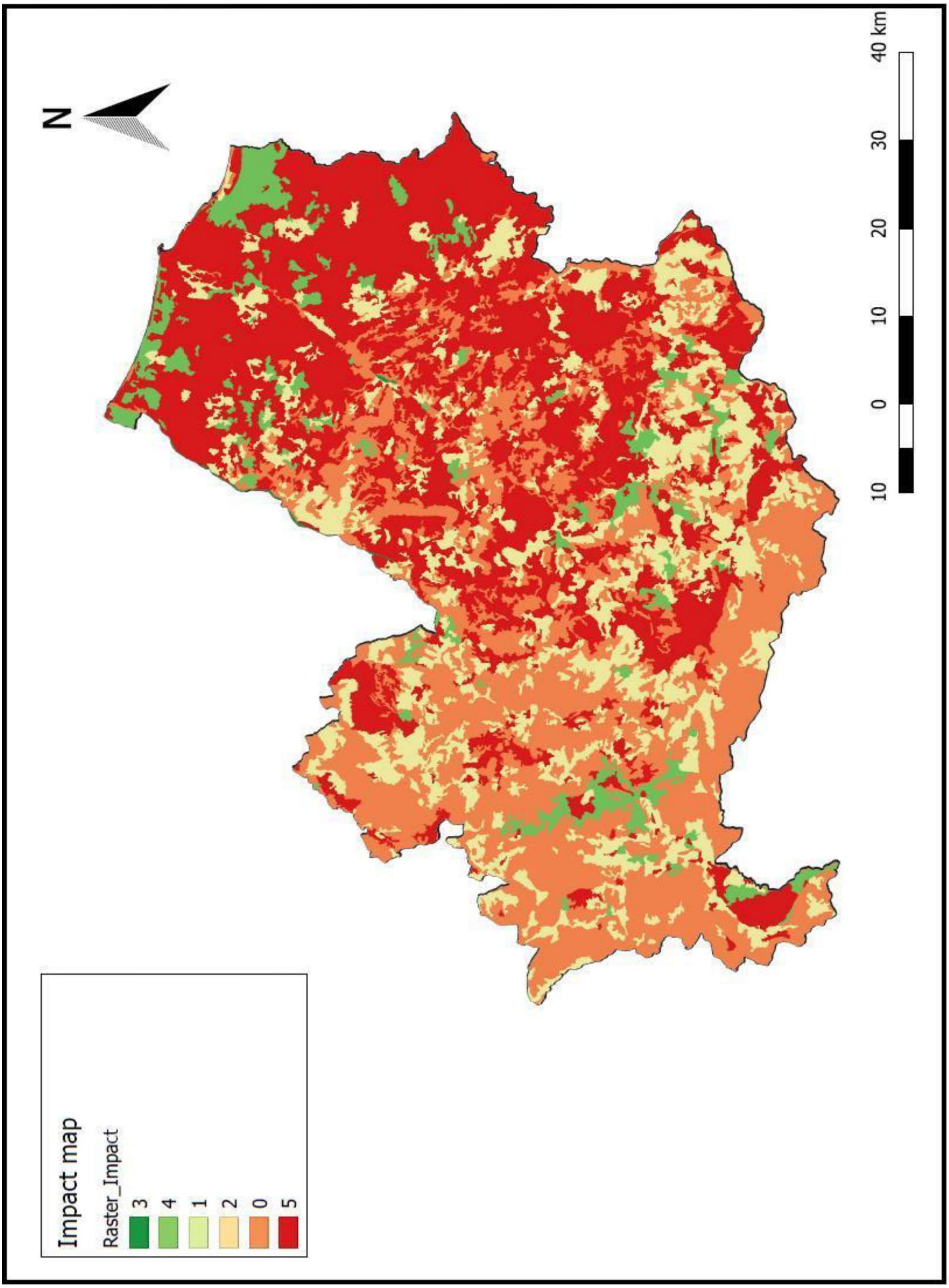

Figure 3: Impact map of Molise Region in raster format (cellars 10m x 10m)

c. Road accidents caused by wild boars and relationship with damages

Geo-referenced data concerning the road accidents in Molise Region, were collected (http://www3.regione.molise.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/218). This data was not included as a direct parameter for the creation of the impact risk maps since they are not contemporary and does not completely cover the total regional surface but only a portion of it. It was carried out an analysis of the environmental characteristics of the neighbouring raster considering the presence of roads especially with accidents events. It was referred to the protocols for the wildlife habitat suitability model of the Molise Region (D'Amico, 2015). The geo-referenced damages were overlaid with the impact risk map. The results of the analysis were verified with R-cran (R-cran, 2021) using the stats package, (Saito and Rehmsmeier, 2016). The presence of significant differences in environmental characteristics between roads with presence of damage and roads with no damage was verified by the Mann-Whitney U Test (Legendre and Legendre, 1998). Subsequently, resource selection functions were formulated (Resource Selection Functions, Boyce and McDonald 1999; Boyce et al., 2002) and in particular both damage presence / absence models (MacKenzie,2005). The damage presence / absence model was created through binary logistic regression analysis (ARLB), comparing the environmental characteristics inside the cells with the presence of the road accident caused by the species with those of cells with no damage in the entire territory of the Molise region. ARLB is based on the following equation:

$$P = \frac{exp^y}{(1 + exp^y)}$$

with P representing the probability of the event happening (in this case the probability of damage) and y is the characteristic equation of multiple linear regression:

$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n$$

where x_n is the nth independent variable and β_n is the standardized coefficient of the independent variables. The variables to be included in the models were chosen following the Information - Theoretic Approach (Burnham and Anderson 2002) and using the Akaike criterion as a comparison parameter (AIC, Akaike Information Criterion, Akaike 1973). As the best model, the one with the minimum AIC and subsequent elaborations were chosen. The reliability and effectiveness of the model were evaluated by testing various parameters:

- *collinearity of the variables, using the Variance Inflation Factor (VIF) using 3 as the threshold value* (Zuur et al., 2010);

- *normality of the residues, through the Kolmogorov-Smirnov test* (Legendre and Legendre, 1998);

- *autocorrelation of residuals, through the Durbin-Watson test* (Quinn and Keough, 2002);

- *discriminatory ability of the model through the ROC curve (Receiver Operating Characteristic plot) and the area under the curve (AUC, Area Under the Curve)* (Pearce and Ferrier, 2000; Boyce et al., 2002; Fawcett, 2006);

- *variance explained, through Nagelkerke's R2* (Legendre and Legendre, 1998).

Before proceeding with the formulation of a resource selection function, the presence of significant differences in the environmental characteristics between roads with the presence of damage and those with roads with no damage was analysed using the Mann-Whitney U test. For the formulation of the model of presence / absence of damage (cells adjacent to the roads), the use of the land was compared between 50 roads with the presence of damage and 20 roads with no damage. In particular, the percentage covers of the following land uses were compared:

- Urbanized areas

- Non-irrigated arable land

- Vineyards

- Orchards

- Olive groves

- Meadows and pastures

- Heterogeneous agricultural areas

- Coniferous and mixed forests

- Areas with sparse and evolving vegetation

3. RESULTS AND DISCUSSION

Table 3 shows the data relating to the areas (ha) in relation to the different levels of impact and to the different categories. These maps are of fundamental importance for the definition of problem areas (also known as non-vocate) to ungulates, as provided by ISPRA.

Table 3: Different levels of impact referred to the different categories

Category	Impact level	Area (ha)	Area (%)
No Impact	0	147.896,99	33
Not significant impact	1	-	-
Arable lands, low impact	2	89.117,20	20
Permanent crops, probable impact	3	303,84	1
Valuable cultivated areas, very probable impact	4	27.478,99	6
Urban areas, high impact	5	178.813,80	40

It was processed a file representing the areas where it was most relevant to carry out the control of the species pursuant to art. 19 L.N. 157/92, with the aim to contain the number of heads. Concerning wild boars, by selection the polygons having the higher level of impact (3-4-5 levels, respectively for permanent crops, valuable cultivated areas and urban areas) it was processed a new polygonal vectorial file that allowed to identify only the areas where the wild boar had a considerable impact. The polygons with the codes of roads in a wooded environment (codes 122) and those with a surface area less than 1 hectare were removed. A buffer function was processed for the remaining polygons; it allowed to create a buffer zone of 300 meters from them. Finally, with the dissolving function, the previous buffers were merged into a single file. The file processed for each impact area were called the “Intervention Area”. In this way it was observed that the intervention areas for wild boar control overlap with the areas where the risk of impact is greatest (Figures 4 and 5).

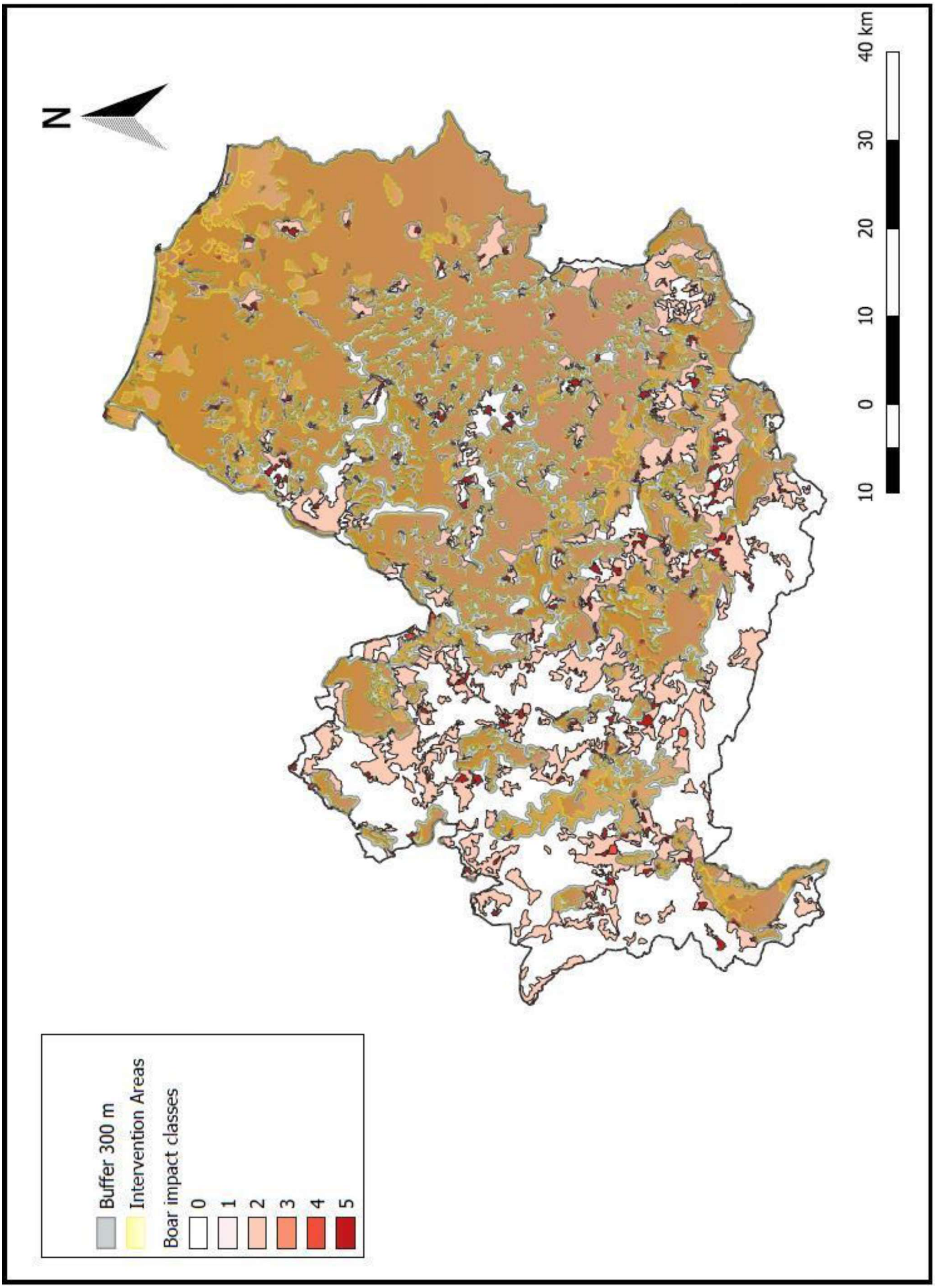

Figure 4: Intervention areas and Impact map

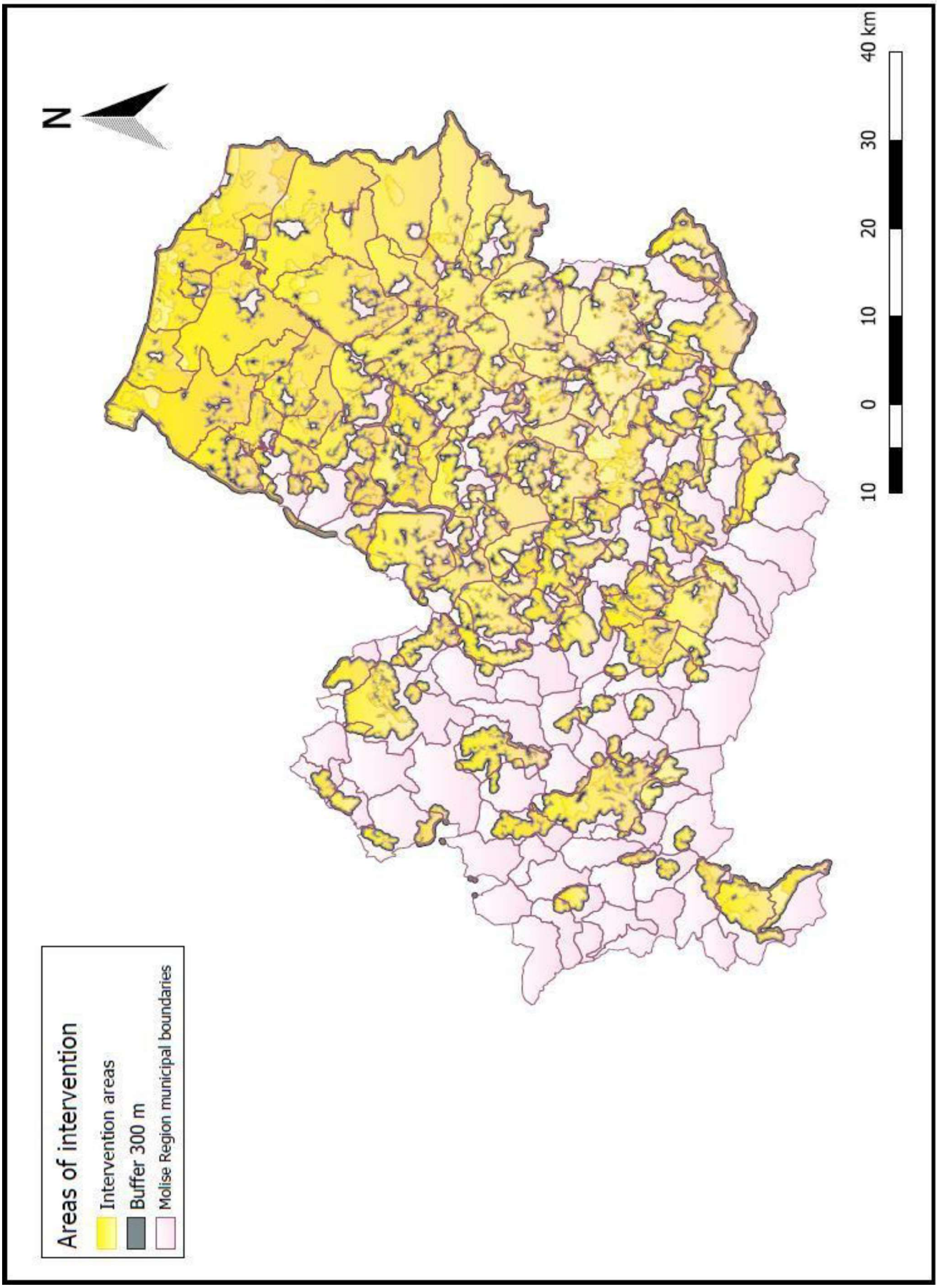

Figure 5: Intervention areas

By comparing the surfaces (ha), it was observed that the areas to be subjected to the control interventions represent only a part of the entire surface of the regional district (Table 4).

Table 4: Areas to be subjected to the control interventions

Total Surface	Agricultural and Forest areas	Intervention areas	Impact level	%	ha
443.613,80	436,465.40	196,598.81	0	//	//
			1	//	//
			2	//	//
			3	0,10	194.61
			4	12,91	25,387.37
			5	86,99	171,016.80

Table 5 shows the differences in the environmental characteristics between roads with the presence of damage and those with roads with no damage, according with the Mann-Whitney U test. The test showed significant differences with the adjacent cells for the following variables: non-irrigated arable lands, vineyards and fruit trees, olive groves, meadows, heterogeneous agricultural areas, wooded areas and areas with sparse and evolving vegetation. In fact, all these variables showed higher values in the road sections of the municipalities with the presence of damage.

Table 5: Environmental characteristics between roads with the presence of damage and those with no damage (Mann-Whitney U test)

Environmental variable	**Median**		**P**
	0	1	
Urban areas	0,375	0,43	0,09
Not irrigated arable lands	10,66	16,41	<0,001
Vineyrads and fruit trees	0,2755	0,2985	<0,001
Olive groves	1,8615	1,3965	0,012
Permanent lands	0,891	0,219	<0,001
Heterogenous agricultural areas	7,31	7,285	<0,001
Wooded lands	11,79	14,975	<0,001
Deciduous forest	11,79	13,07	<0,001
Coniferous forest	0,102	0,4105	<0,001
Mixed forest	0,237	0,21	<0,001
Meadows and pastures	1,777	2,105	0,176
Areas with evolving vegetation	1,325	1,57	<0,001
Sparsely vegetated areas	0,077	0,2455	<0,001

The damages are positively influenced by not-irrigated arable land, heterogeneous agricultural areas, coniferous forests and by areas with sparsely vegetated areas; a negative influence was observed in vineyards and orchards (Table 6).

Table 6: Best model obtained from binary logistic regression analysis: coefficients (β), standard error (ES) and inflation factor of variance (VIF).

Environmental variable	β	ES	VIF
Intercepts	-0,1795	0,256	//
Not irrigated arable lands	0,008	0,004	1,278
Vineyrads and fruit trees	-0,176	0,1005	2,082
Heterogenous agricultural areas	0,0115	0,007	2,193
Coniferous forest	0,508	0,134	0,844
Sparsely vegetated areas	0,277	0,174	1,975

The variance inflation factor (VIF) did not show any correlation between the variables (VIF <3; table 6) and the ability of the model is weak but should be implemented with more data for further verification, with the AUC of the ROC curve of 0.754 (P <0.001) (figure 6). The residuals are not normally distributed (Kolmogorov-Smirnov test of normality, D = 0.436, P <0.001) and are not autocorrelated (Durbin-Watson autocorrelation test, DW = 1.85, P = 0.343). The variance explained by Nagelkerke's R2 is equal to 0.234.

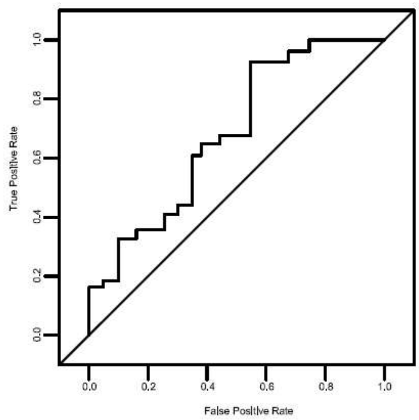

Figure 6: ROC curve of the model presence/absence of damages by wild boars close with the roads in Molise Region

The layers of Protected Areas and Natural Reserves, Oases and Restocking and Capture Areas (ZRC) have been merged with the intervention map (Figure 7). The areas of intervention overlap in most part of cases the areas with road accidents, because they play a refuge effect (Amici et al. 2012) for the species, where the wild boar is not disturbed by anthropogenic activity and has no pressure by hunting; it might be thought that the wild boars use these spaces as day shelter and/or breeding areas (IUCN-WCPA, 2019).

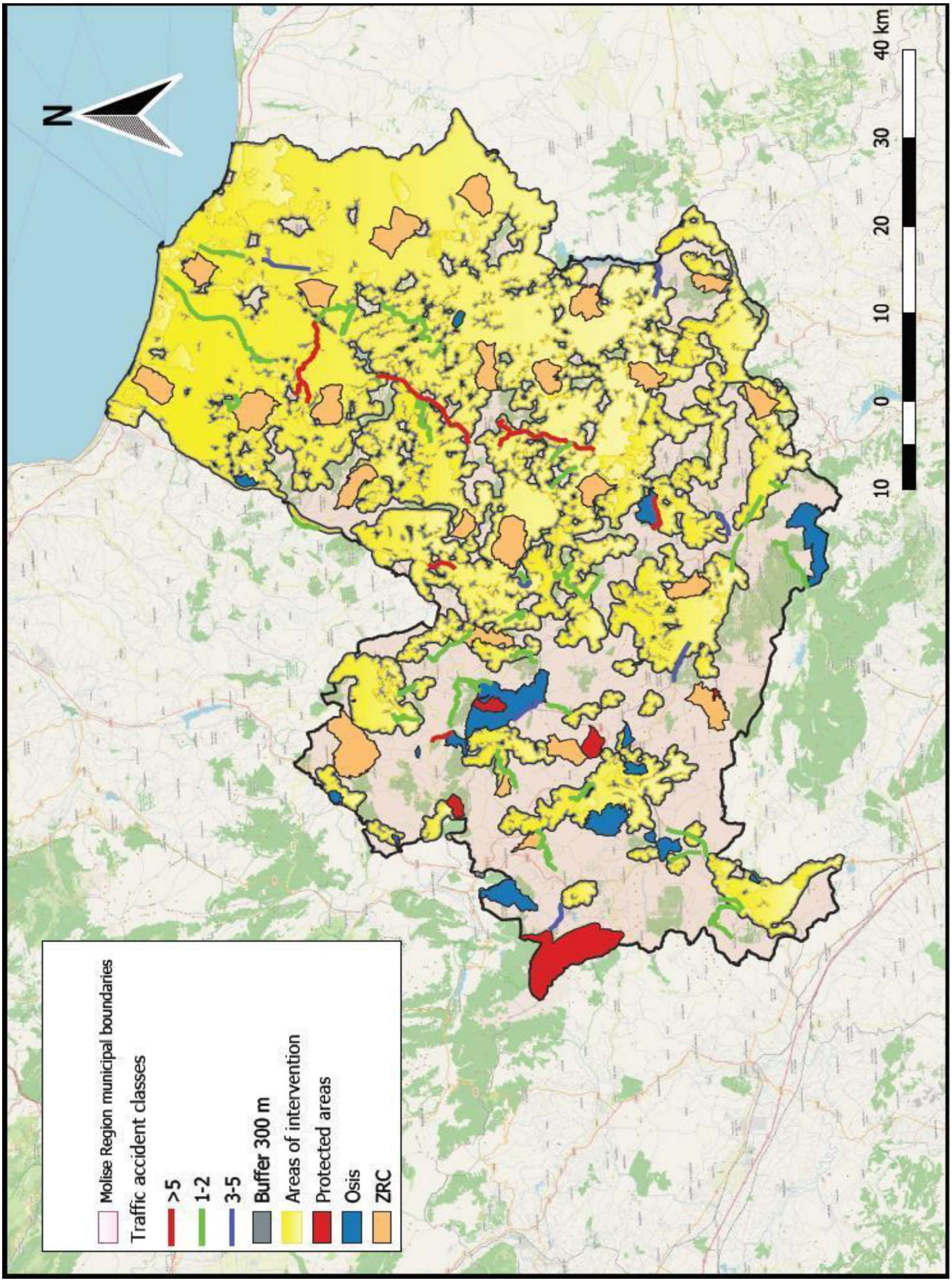

Figure 7: Intervention map merged with Protected Areas, Oasis and Capture Areas (ZRC); relationship with roads accidents

4. CONCLUSIONS

The geo-referenced damage of wild boars demonstrates how almost all the damages are concentrated in the areas where road accidents have occurred and where there is the maximum risk of impact. The impact maps of the ungulates are fundamental tools to define the non-suitable / problematic areas mainly in the case of non-conservative management of the species, especially where the Human-wildlife conflict is more evident. These studies could be improved by identifying the portions of the territory where to carry out the control operations pursuant to art. 19 L.N. 157/92. These areas should be managed through control interventions (Perco, 2020), adequate local studies of territorial analyses and different methodologies for fauna management and biological analysis of the species (Mills et al. 1999). These maps represent a good starting point for the management of the territories, in order to develop the best strategy from a technical and economical point of view. In this way it will be possible to involve the different organizations (public authority, associations, hunting organizations, etc.) to cooperate in the active and adaptive management of wild boars developing management plans to reduce the damages.

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PART II

Wild Boar in urban and peri-urban areas: corridor elements of the landscape in an urban area of Southern Italy

Submitted to the journal: *Human–Wildlife Interactions* (*HWI*)

ABSTRACT

The population numbers and the geographical range of wild boars have been growing all over Europe for nearly five decades and reports on wild boars in urbanised areas, along with human-wild boar conflicts, are increasing. Yet, an increasing number of cities throughout the world are registering conflicts due to the presence of different species of wild animals. Due to the recent increase in human–ungulate conflicts, there is a need to plan programs for urban wildlife management with the objectives to control their movement and to limit the number of heads. This article describes the analyses of an urban and peri-urban context in Southern Italy where sightings of wild boars have occurred. The corridors passages were studied through physical-ecological elements of the landscape to which the species is linked. Three maps concerning the wild boar presence in the Municipality, the physical territorial elements and the ecological elements of the city were elaborated and the different levels of components that characterize the territory were extrapolated. The cartography of the study was planned by using a GIS software. The R software was used for the statistical analysis (R- Cran, 2022). Once the map of the ecological network of the Wild Boar has been created, for a verification and link of this species to the identified ecological elements, the Corine Land Cover of III level of 2018 (Copernicus EU, 2016) was superimposed, dividing the categories of the Corine Land Cover (Cod_CLC_18) in two macroclasses: Urban areas and Peri-Urban (Periurban) areas. The sightings of wild boars within the city are linked to wooded areas (stepping stones), including scattered hedges that wild boars use for short and fast movements and the proximity of ecological corridors for greater distances. These animals pass through these corridors identified with this model because they are located in the proximity of feeding sites (urban waste and agricultural crops) or close to water and mud areas that they also use for land coverings. These corridors should be monitored and managed, activating specific programs, with geo-referenced photos and videos implementing a database of wild boar sightings. This system gives the possibility of continuous monitoring of the species in an urban environment and permit to verify the presence of these animals in real time.

KEYWORDS: wild boars, urban and peri-urban areas, corridor passages, urban wildlife conflicts, wildlife monitoring.

1. INTRODUCTION

At the end of 20th Century many populations of wild ungulates increased considerably and recolonised large areas following a multicontinental phenomenon (Boulanger et al., 2018). At a local level, populations of ungulates in Europe have reached situations defined as overabundance in some areas, with detrimental effects on biodiversity and ecosystem function (Valente et al., 2020). In this context the expansion of urban areas and the increase of anthropogenic phenomenon is one of the most important threats to biodiversity, as it reduces species richness, alters species composition and increases biotic homogenisation (Leong et al., 2016). Moreover, urban habitats entail novel challenges to wild individuals and populations, including anthropogenic disturbances such as human presence and traffic noise (Fernández-Juricic and Tellería, 2000), exposure to toxic substances and increased disease transmission (Murray et al., 2019). The key to survive in human-altered habitats is to adapt to the new selection pressures, which can induce changes in behaviour, morphology, physiology as the genetic structure of animal populations (McDonnell and Hahs, 2015). The response of larger mammals to urbanisation have been less studied; yet, an increasing number of cities throughout the world are registering conflicts due to the presence of large carnivores and ungulates such as carnivore species (Salek, 2015), red deer (*Cervus elaphus*), fallow deer (*Dama dama*) (Valente et al., 2020) or wild boar (*Sus scrofa Linnaeus 1758*) (Stillfried et al., 2017a; La Stampa, 2021). These conflicts commonly include traffic accidents, property damage and risk of attacks and of disease transmission (Soulsbury and White, 2015). The population numbers and the geographical range of wild boars have been growing all over Europe for nearly five decades (Massei et al., 2015), and reports on wild boars in urbanised areas, along with human-wild boar conflicts, are increasing (Licoppe et al., 2013). Understanding the mechanisms that allow individuals and populations to deal with urban environmental change is essential to estimate the impact of urbanisation on wildlife (McDonnell and Hahs, 2015). Moreover, this knowledge will be useful to design better management practices aimed at reducing the human-wildlife conflicts in urbanised environments. Peri-urban and urban areas are characterised by built-up areas connected by roads and highways, as well as green areas composed of a mosaic of patches of various types, such as gardens, squares, road verges, playgrounds, allotments, orchards, parks and cemeteries (Ciach and Fröhlich 2019). In this context, the main overabundant ungulate species are the wild boar and roe deer (Carpio et al., 2021). Ungulates may be attracted by (peri)urban areas because of the improved habitat (Kilpatrick et al. 2011), the lack of predators or increased opportunities for feeding (Conejero et al., 2019). Other aspects that improved the expansion of wild animals in urban areas (Amendolia et al. 2019), have been rivers and roads acting as the main movement corridors (Stillfried et al. 2017b). Other elements that increased this phenomenon are the hunting restrictions (Sterwart 2011), because hunting is often forbidden in urban areas (Storm et al. 2007). These circumstances determined a process of habituation (Geist 2011,) with an absence or decrease in the 'landscape of fear' (Stillfried et al. 2017b), resulting in a process of semi-domestication (Mysterud 2010). In this context, the overabundance of ungulates causes a series of conflicts, grouped mainly into: ungulate vehicle collisions (Zuberogoitia et al. 2014), nuisance to humans (Duarte et al. 2015) and transmission of zoonotic disease (Vourc'h et al. 2016). Due to the recent increase in human–ungulate conflicts, there is a need for urban wildlife management (Martin et al.,2020) with the objectives to control animal movement and reduce population size in order to avoid conflicts (Reidinger & Miller 2013). This article describes the analyses of an urban and peri-urban context where sightings of wild boars occur; the corridors passages were studied through physical-ecological elements of the landscape to which the species is linked.

2. MATERIAL AND METHODS

a. Study area

The study area analysed is the municipality of the city of Campobasso, in Southern Italy (41 ° 33'36 "N, 14 ° 39'45" E), capital of the Molise Region, with a population of 49,262.00, with a density of 877.95 inhabitants per square kilometre and an average altitude of 701 meters above sea level. In this region there are two Sites of Community Importance (SCI), Special Areas of Conservation (SAC):

1) Rocca Monforte (code IT7222125), extended for an area of 26.00 ha, geographical coordinates (decimal degrees) longitude 14.6539 and latitude 41.5639, position in the urban center.

2) Monte Vairano (code IT7222295), extending over an area of 620.00 ha, geographic coordinates (decimal degrees) longitude 14.6028 and latitude 41.5531, position in the peri-urban area of the city to the west (ISPRA, 2021).

Within the study area, there is the presence of multiple minor water bodies such as canals, rivulets, ditches and streams (Southern Apennine District Basin Authority, 2021). From what emerges from national statistical studies, the city of Campobasso has a public green index, relating to square meters for habitant, equal to 11.16 (ISTAT, 2021). Table 1 shows the description of urban and periurban areas in the region of Campobasso.

b. Data collection and sampling

To detect the presence and sightings of the wild boar in the city of Campobasso, a bibliographic survey was carried out on local newspapers that reported wild boars sightings in the years 2018 to 2021, as well as a search for photos and videos on media networks (Facebook, Instagram). The sightings were mainly reported by citizens, who informed of the presence of a single minimum animal detected, up to 12 animals detected.

To avoid replicas and detect the same animals in different newspapers, the data was analysed in relation to the position on the map.

c. Data creation maps

In an urban context it is necessary to focus on the various components that in an ecological network have priority over the behavior for a species. The ecological network is made up of these main components: patches, ecological corridors and stepping stones. The patch is a corridor that facilitates the movement of populations and/or individuals, in term of minutes, hours, or over multiple generations of a species. (Hilty et al, 2019). For the creation of the map of the ecological network of the city of Campobasso different levels of components that characterize the territory were extrapolated. In this case the territorial levels represent layers that were used in raster format with 10x10m pixel resolution. The HRL Forests (High Resolution Layer – Copernicus Land Monitoring Service, 2018) products are available for 2018 reference years; the download layers are: tree cover density (TCD) (level of tree cover density in a range from 0-100%); the level of sealed soil (imperviousness). The status layers are available in 10m spatial resolution (2018). Other three products have only one previous reference year (2015) (Grassland, Water and Wetness products and Small Woody Features).

- The imperviousness products capture the percentage and change of soil sealing. Sealed/Impervious areas are characterized by the substitution of the original (semi-) natural land cover or water surface with an artificial, often impervious cover. These artificial surfaces are usually maintained over long periods of time. The imperviousness HRL captures the spatial distribution of artificially sealed areas, including the level of sealing of the soil per area unit. The level of sealed soil (imperviousness degree 1-100%) is produced using a semi-automated classification, based on calibrated NDVI (Normalized Difference Vegetation Index). In particular the layers: Imperviousness Density (IMD). The percentage of sealed area is mapped for each status layer for any of the 5 reference years (e.g. degree of Imperviousness 2012). The status layers are available in 10m spatial resolution (2018).

The Grassland (GRA): the main product is a binary grassland/non-grassland product in 10m (2018) pixels size, that includes the full spectrum of grassland use intensity (from natural to managed grasslands).

- The Road Network of the municipal area of the city of Campobasso: the status layers are available in 5m spatial resolution (2021).

- The combined Water and Wetness (WAW) product is a thematic product showing the occurrence of water and wet surfaces over the period from 2009 to 2018. The products show the occurrence of water and indicate the degree of wetness in a physical sense; it is assessed independently of the actual vegetation cover and is not limited to a specific land cover class; their relative frequencies product is in 10m (2018).

By combining these information layers, a map of physical elements that characterize the territory was created. An index of importance (from 0 to 10) has been created for wild boar according to the characteristic elements of the territory and the biological and ethological link. The cartography of the study was planned by using a GIS software (QGis 3.16, Hannover, GNU license - General Public License).

d. Statistical analysis

The R software was used for the statistical analysis (R- Cran , 2022). Given the low number of sightings and data (22 Sightings in the period years 2018 to 2021), after having tested the homoskedasticity and distribution of the data (Schluter, 2010), it was used a non-parametric statistical analysis, the Kruskall Wallis Test (Ostertagova, E et al, 2014): the function "Kruskal.test" is part of R software (R core Team, 2022) from the 'stats' package. In order to test the correlation between the number of animals sighted and the environmental variables analysed in the buffers, a non-parametric test was carried out, the Spearman's Test (Bill et al, 2019); the correlation eith Spearman's test method has been calculated with the statistical software R (R – Cran , 2022).

3. RESULTS

22 different observations were recorded in the municipality of Campobasso and subsequently these sightings were geo-referenced, precisely finding the exact point of the sighting and reported in figure 1. Concerning the landscape parameters, it was confirmed the importance of the wooded edges close to cultivations, the presence of rivers as ecological corridors (1-km buffer in intensively used farmland). The same was observed for water availability, and the lower human presence (Amici A., 2012). Analysing the ethology and biology of the wild boar, the species is opportunistic, but is mainly linked for shelter to wooded environments and waterways (Tack, J., 2018). The index of importance (from 0 to 10) has been created for wild boar according to the characteristic elements of the territory and the biological and ethological link.

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0: Impervious Density (IMD)
1: Road network
3: Grassland
5: Tree cover density, hedges, shrubs, urban parks etc. that are not woods
7: Water and waters
10: Tree cover density, referring to the set of rasters that form a forest according to Italian law (Cerfolini, 2014), and that match the city limits (Bar-On et al, 2018).

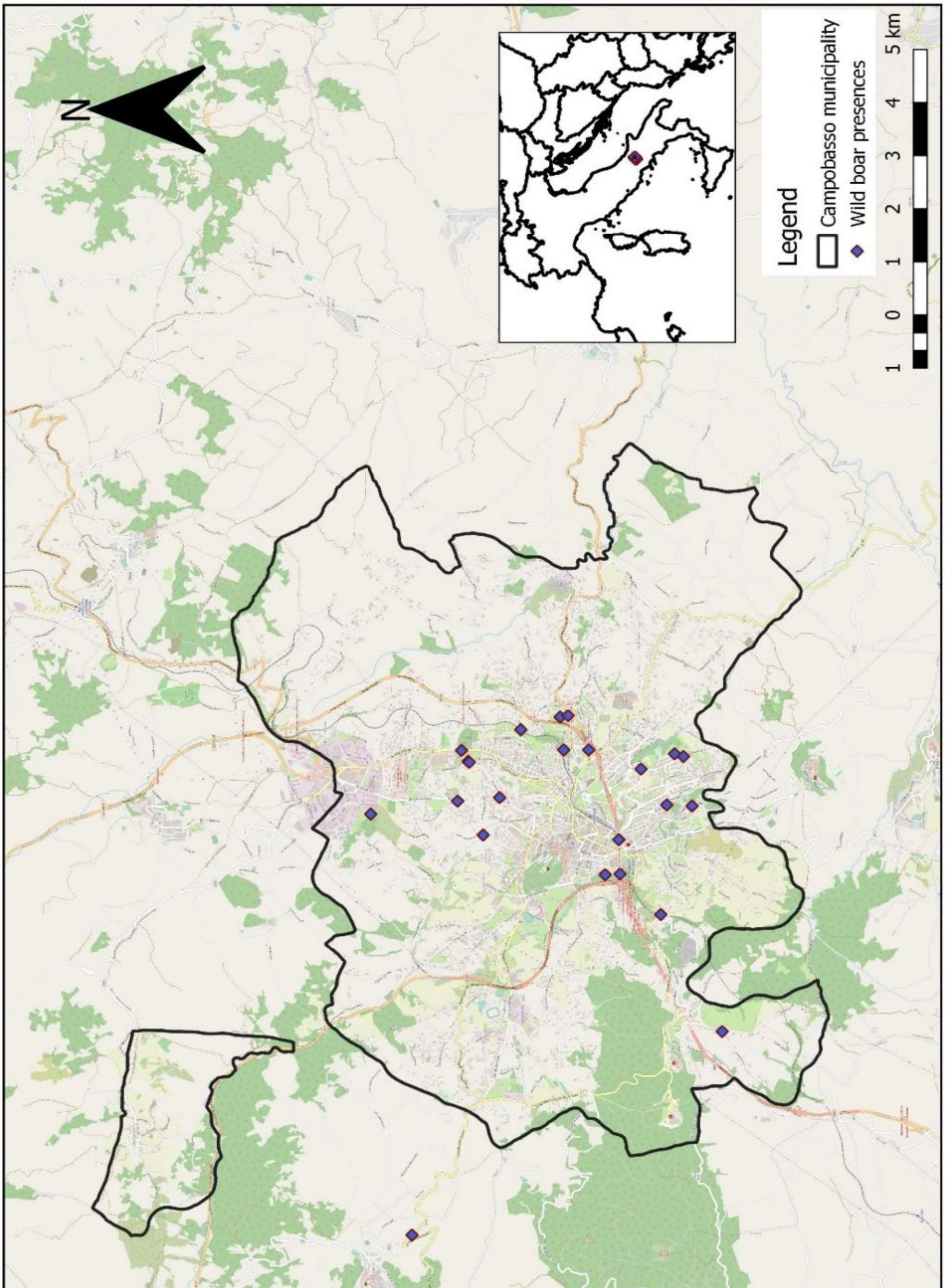


Figure. 1: Campobasso Municipality and Wild boar presence

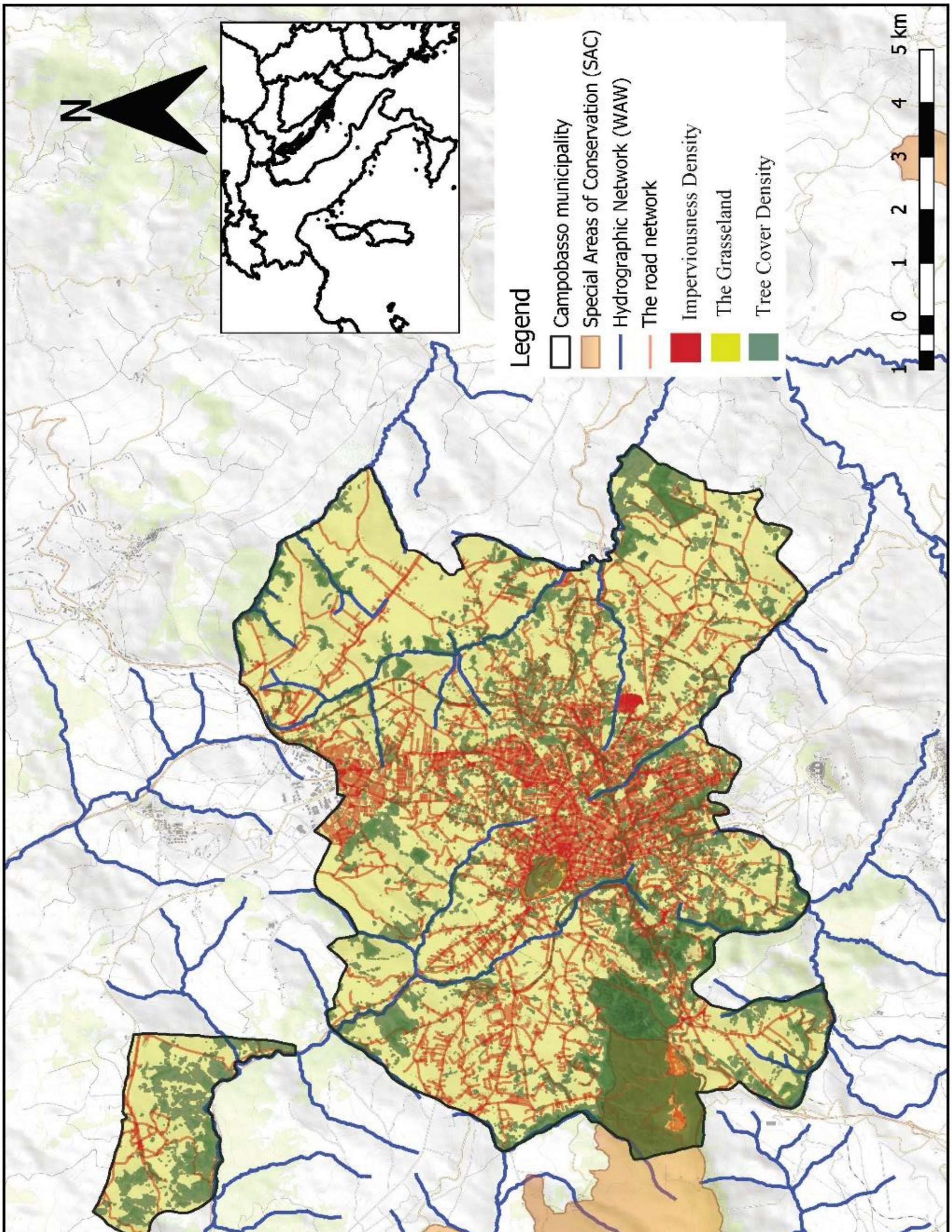
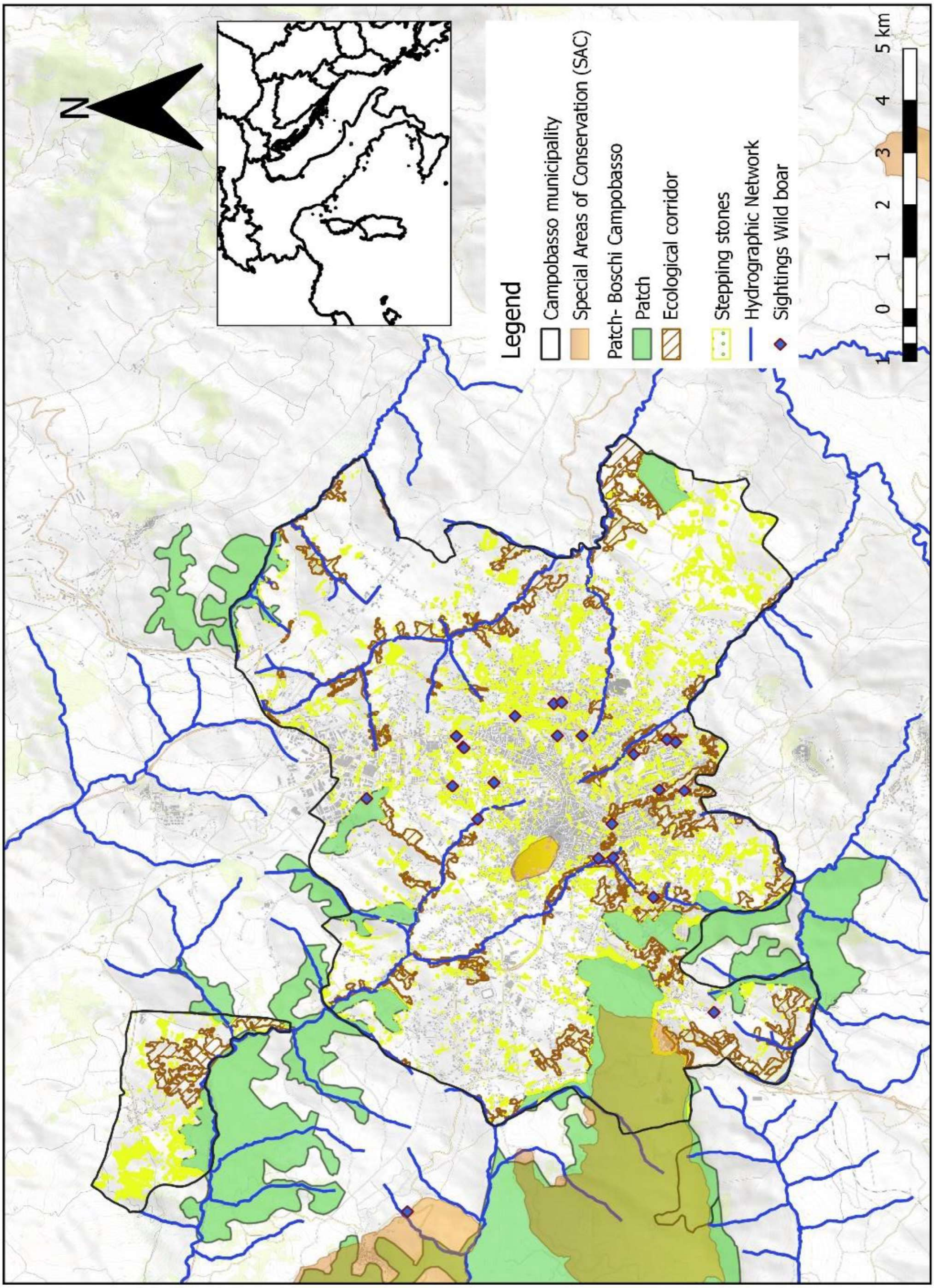


Figure. 2: Map of territorial elements

Figure 3: Map of the ecological elements of the city of Campobasso



By adding up the different values attributed to the pixels of the raster, the various components of the ecological network to which we have given the thresholds were identified (Figure 3):

- Other elements not significant for the species less than 5
- Stepping stones values between 5 and less than 10
- Patch value equal to 10
- Ecological corridors value greater than 10

Once the map of the ecological network of the Wild Boar has been created, for a verification and link of this species to the identified ecological elements, the Corine Land Cover of III level of 2018 (Copernicus EU, 2016) were superimposed, dividing the categories of the Corine Land Cover (Cod_CLC_18) in two macroclasses: Urban areas and Peri-Urban (Periurban) areas (Brook, R, 2000) (Table 1). We superimposed on this the sightings of wild boars and we created a buffer with a radius of 300 linear meters (28.26 ha of surface), analysing some environmental variables that fall into this area: Number of animals sighted (NA), Number of ecological corridors that fall into the buffer (NC), Number of Stepping stones (NS), Number of Patches (NP), Average Distance from Patches in meters (DmP), Average Distance from Watercourses in meters (DmW), Average Distance from Ecological Corridors in meters (DmC) , Arborated Surface in hectares (ST), Landscape Surface in hectares (SG), Anthropized Surface in hectares (SI), Total Sightings (TS)(Rawelle, 2021) (Table 2).

Cod_CLC18 City of Campobasso	Description	Zone (Urban or Periurban)
111	Continuous urban fabric	Urban
112	Discontinuous urban fabric	Urban
121	Industrial or commercial units	Urban
211	Non-irrigated arable land	Periurban
242	Complex cultivation patterns	Periurban
243	Land principally occupied by agriculture, with significant areas of natural vegetation	Periurban
311	Broad-leaved forest	Periurban
321	Natural grasslands	Periurban
324	Transitional woodland-shrub	Periurban

Table 1: Description of urban and periurban areas in the region of Campobasso

	Mean	Sd	Median	Trimmed	Mad	Min	Max	Skew	Kurtosis	Se
ID	11,50	6,49	11,50	11,50	8,15	1,00	22,00	0	-1,36444484	1,38443731
NA	5,18	5,36	3,00	4,39	2,97	1,00	21,00	1,28028339	0,99910383	1,14270955
NC	0,77	0,87	0,50	0,72	0,74	0,00	2,00	0,4205369	-1,6022981	0,18530212
NS	18,18	7,47	17,00	17,50	7,41	9,00	36,00	0,73403873	-0,4526494	1,59359699
NP	0,18	0,50	0,00	0,06	0,00	0,00	2,00	2,52602876	5,5406074	0,10683085
DmP	1979,10	1108,43	1890,99	1989,83	1291,50	22,17	3899,03	-0,03656826	-1,09329295	236,317118
DmW	539,28	326,06	515,06	546,84	426,77	29,69	982,52	-0,12128454	-1,49840242	69,516693
DmC	354,97	354,59	322,21	329,94	477,70	0,00	939,65	0,32413861	-1,57765454	75,5998625
ST	3,64	3,16	2,69	3,32	2,60	0,17	10,30	0,80507058	-0,75822294	0,67469168
SG	11,57	5,31	10,20	11,21	4,36	3,36	23,62	0,62678623	-0,51814699	1,13186311
SI	13,05	5,03	13,04	12,91	5,90	3,92	24,42	0,24798024	-0,67982557	1,07317602

Table 2: General statistical descriptive of the environmental elements in the 300 m buffers

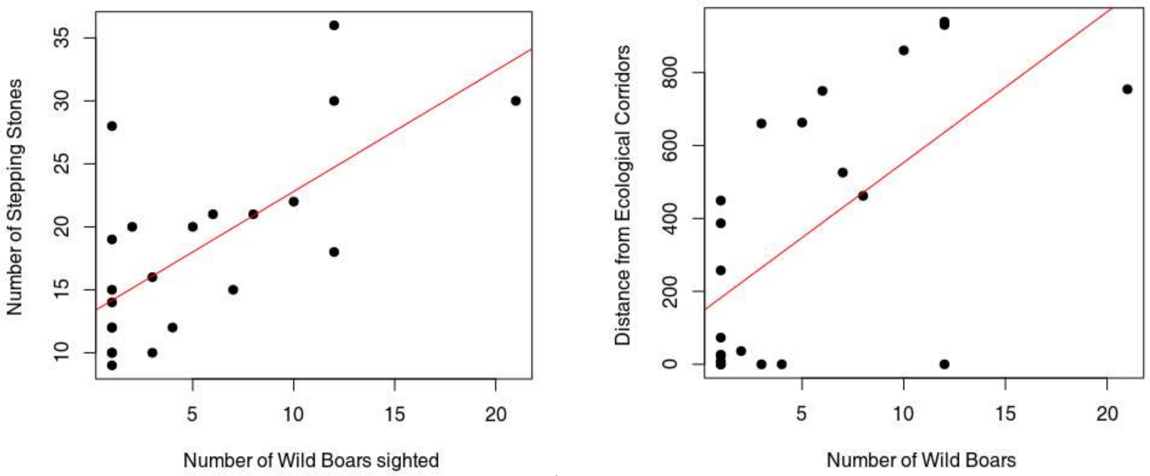
	Urban Area							Periurban Area							K-squared	P value
	Mean	Sd	Medium	Min	Max	Range	Se	Mean	Sd	Median	Min	Max	Range	Se		
Na	6,75	6,30	4,50	1,00	21,00	20,00	1,82	3,30	3,37	1,00	1,00	10,00	9,00	1,0651	24.747	0.1157
NC	0,75	0,97	0,00	0,00	2,00	2,00	0,28	0,80	0,79	1,00	0,00	2,00	2,00	0,24944	0.082353	0.7741
NS	20,75	8,44	19,00	10,00	36,00	26,00	2,44	15,10	4,89	13,00	9,00	22,00	13,00	1,54524	23.157	0.1281
NP	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,40	0,70	0,00	0,00	2,00	2,00	0,22111	3.96	**0.04659**
DmP	2157,12	1015,45	1890,99	1007,65	3899,03	2891,38	293,13	1765,48	1230,25	1825,20	22,17	3400,71	3378,54	389,039	0.35217	0.5529
DmW	613,40	335,21	709,27	29,69	973,55	943,86	96,77	450,33	307,60	390,21	35,24	982,52	947,28	97,2727	12.565	0.2623
DmC	422,55	387,74	487,44	0,00	939,65	939,65	111,93	273,87	310,22	165,40	0,00	860,86	860,86	98,0998	0.5321	0.4657
ST	2,70	2,22	2,00	0,38	7,16	6,78	0,64	4,77	3,84	3,74	0,17	10,30	10,13	1,21436	12.565	0.2623
SG	9,94	5,01	7,54	3,36	18,45	15,09	1,45	13,52	5,22	11,74	8,74	23,62	14,88	1,65096	34.087	0.06485
SI	15,62	4,64	16,08	8,20	24,42	16,22	1,34	9,97	3,66	10,02	3,92	16,26	12,34	1,15879	69.565	**0.008351**
Ts	12,00							10,00								

Table 3. Environmental variables of the buffer area in the Urban and Priurban areas macro-categories

The Kruskall Wallis Test was used for the comparison of the variables divided into the two Urban and Periurbane areas; only two variables significantly distinguished the two areas (P value <0.05): the Number of Patches (NP) 0.04659 and the man-made surface (SI) 0,008351. In these two areas there are no significant differences in the number of herds of sighted. Consequently, the characteristics of the sightings areas are homogenous. The analysis of data by the Spearman's Test (table 4) shows that the environmental variables that significantly influence the number of flocks (P value < 0.01) are the Number of Stepping stones (NS) 0.0007505 and the Distance of sightings from Ecological Corridors (DmC) 0.005242. The 'graphics' package is part of R. (R core Team, 2022) (Figures 4a and 4b).

Environmental variable	S	r	P value
NC	2278.3	-0.2864501	0.1962
NS	594.89	0.6640956	**0.0007505*****
NP	2517.1	-0.4212812	0.05086
DmP	1725.4	0.02577083	0.9094
DmW	1404.8	0.2067524	0.3559
DmC	754.94	0.5737213	**0.005242****
ST	1999.2	-0.1288542	0.5677
SG	1729.5	0.02342803	0.9176
SI	1346.8	0.2395516	0.2829

Table 4: Correlation with the Spearman's Test, between the number of sightings and environmental variables, P value < 0.001 *** and 0.001 to 0.01 **



4a **4b**

Figure 4: Correlation between number of animals sighted (P value < 0.001 ***) and number of stepping stones (4a) and correlation between number of animals sighted and distance from ecological corridors in meters (P value 0.001 to 0.01 **) (4b).

4. DISCUSSION

The sightings of wild boars within the city are linked to wooded areas including (stepping stones), such as scattered hedges that wild boars use for short and fast movements and the proximity of ecological corridors for greater distances. Generally, animals keep close to these ecological structures to escape anthropogenic disturbances such as stray dogs, vehicle traffic etc. (Stolba et al., 1989), as well as being safe shelters for the species. These animals pass through these corridors identified with this model because they are located in the proximity of feeding sites (urban waste and agricultural crops) or close to water and mud areas that they also use for land coverings. Therefore, these corridors should be monitored and managed, activating citizen science programs, eg. creation of an App for mobile phones, which record geo-referenced photos and videos where the same citizen with simple sighting and recording increasingly implements a database of wild boar sightings; this system gives the possibility of continuous monitoring of the species in an urban environment and permit to verify the presence of these animals in real time. The data could be easily reported to technicians and to the political decision-maker and, in order to implement and understand the causes that push these animals towards the city and activate management and control measures of the species in a dynamic way.

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PART III

Estimation of the Wild Boar Population in Southern Italian Apennines by Pellet Count Group Technic: A Preliminary Study

Published in the journal: *Emerging Challenges in Environment and Earth Science Vol.2*
DOI: 10.9734/bpi/ecees/v2/1807A
Published: 2022-02-11

Cite:
Aldo, D. B., & Nicoletta, M. (2022). Estimation of the Wild Boar Population in Southern Italian Apennines by Pellet Count Group Technic: A Preliminary Study. *Emerging Challenges in Environment and Earth Science Vol. 2*, 45–55. https://doi.org/10.9734/bpi/ecees/v2/1807A

ABSTRACT

Today the development of wild ungulates represents one of the most relevant changes of the Italian wildlife in the last decades. The occurrence of damages by wild boars raised dramatically in the last decades and amounts to hundreds of thousands of Euros per year in several European countries. Knowledge of distribution, abundance and population dynamics is essential for their correct management, especially for the Wild boar (*Sus scrofa*) considering its impact on the natural and agricultural ecosystem. This paper proposes an estimate of the wild boar population in a study area, located in the south / south-eastern part of the Italian Apennines. The census technique was planned through field inspections and cartographic elaborations using GiS software and the Pellet Count Group technic. The data of the Pellet Group discovery were marked on special field cards. 7.010 linear meters and 14.020 m_2 were crossed; 12 Pellets Group were found. From this database and knowing the extent of each specific habitat it was detected the presence of about 7/8 animals per 100 ha. These densities, projected by the number of hectares of each analysed habitat, indicate a presence of animals ranging between 187 and 164. Considering that, the optimal density for the study area would be about 47 animals per 100 ha, this means that the real density exceeds considerably these values. Therefore, the population within the Park should be reduced through a set-up of a real census plan deriving from different types of census repeated over several years.

KEYWORDS: Wild boar; ecosystem; distribution; abundance; population dynamics; pellet count group.

1. INTRODUCTION

The wild ungulates development represents today one of the most important changes occurred in the past decades in Europe and in Italy. Wildlife is responsible for causing considerable amounts of damage to agriculture, specially to croplands [1,2,3,4,5]. The occurrence of damages by wild boars raised dramatically in the last decades and amounts to hundreds of thousands of Euros per year in several European countries [6,7]. In contrast to many other ungulates, the wild boar is an omnivore and inhabits a vast range of habitats [3]. This situation often determines serious conflicts with humans [8,9]. The wild boar (*Sus scrofa* L.) greatly expanded their distribution areas because of the progressive adaptation to the most varied ecological and environmental conditions linked in most part to modified biological factors [10,11,12,13]. In thirty years, the home-range has quintupled, involving different geographical areas. Wild boars are now diffused from lowlands to hilly and mountainous areas; the presence of wild boars have been observed also in the periphery of urban areas (e.g., Rome). The strong impact that the wild boar has on some activities of economic interest contributes to sharpen the contrasts between social categories (hunters, farmers, foresters, public entities) having divergent interests. The efficiency of hunting, feeding and fencing to reduce crop damage by wild boars was largely studied [14]. The conflict of interests linked to the presence of the wild boar on the territory, together with some difficulties of technical nature (for example related to the quantitative estimate of the population), makes the management of this species particularly problematic. In fact, the management policies are inadequate as the lack of technical organization. Today, the serious lack of money invested by institutions to estimate the wild boars population and its biological characteristics (e.g. potential rates of population growth), together with the limited knowledge in this field determine considerable difficulties to face and solve these problems. The first step in the management policies is to determine the wild boars populations and the possible changes coming out from the territories, appreciating their incidence on the trophic scale in a given environment. The estimation of the density of wildlife is fundamental to improve the management and conservation of this resource [15]. For many years, the scientific community has developed accurate techniques to register these populations through different census applications. These techniques have to be calibrated in relation to the species and the habitats. The outcome will depend on the costs and the number of operators available in the field. In this work, we applied one of these estimation techniques on the local wild boar population: the Faecal pellets Count Group. The Pellets Count Group (PCG) has been widely adopted, for the large-scale monitoring, since its first description in

1940 [16]. It was finalized to obtain a relative abundance index, and used to ascertain the population distribution; moreover, it allowed to analyse the use of the habitat, although the latter use is widely controversial. This technique allowed to develop predictive models, processed through the use of a GIS. Generally, this technique is applied to obtain an estimate of the abundance of ungulates, in environments with extensive forest cover, where other methods cannot be used successfully and are characterized by an unsatisfactory cost / benefit ratio. The basic concept is that the density of pellet groups is related to the average number of animals in the same area for a given period. There are two main types of pellet count: FSC (Faecal Standing Crop) and FAR (Faecal Accumulation Rate). The usual technique consists in counting the number of pellet groups (PG) present within spatial sampling units (transects, UC), selected according to a probabilistic procedure, usually observing a stratification for habitat, in order to improve the accuracy of the result [17]. In this application, the sampling strategy is the most important aspect in the planning phase; the effectiveness of the results depends in most part on it. A preliminary procedure (such as a pilot study) is recommended, in order to verify if the technique is appropriate in relation to: objectives; available economic and human resources; environmental context; distribution of the abundance of the target species. These latter elements strongly influence the sampling procedure and the final result. In particular, the pilot study is functional to the sampling quantification (total length of the paths), useful to obtain estimates values characterized by the desired degree of variability [18]. Another fundamental element is the preparation of the technicians. In fact, the detection error, could indeed represents an important source of variability in the final result. It is therefore necessary that the number of technicians involved is limited and provided of an adequate specific training. Also, the individual reading capacity of the sampling unit should be assessed through a specially planned field test. Before to start the process and the data collection it is important to define the mode of quantification of pellet groups and to establish rules for the treatment and classification of all possible cases. These cases are partly known and treated in specialized literature; however, the execution of the pilot study will help to identify others, helping to standardize the detection mode between technicians. Pellet group is defined as an accumulation of at least 6 pellets produced in the same event [19]. A pellet group needs of at least 6 faecal pellets [20]. When a PG is present on the edge of the sampling unit, its inclusion or exclusion must be established on the basis of the percentage of pellets inside or outside the sampling unit; if the PG is situated exactly on the edge of the sampling unit, it has to be included and excluded from the count alternately [19]. The different ways to carry out the pellet count are characterized by different levels of precision depending in most part on the financial resources, the logistic and organizational aspects. The accuracy of both methods seems strongly influenced by the population density: both are not very effective at low density (<5 heads / km^2), where they would not be able to detect a decrease of 10% of the population, only after many years of monitoring [21]. In the same conditions, the FSC produces more precise estimates than FAR and others technics, although the differences are rather small [20,21]; generally, these differences depend on the accumulation time necessary to apply the FAR. It should be stressed, however, that if accumulation times are too long, the onset of PG deterioration may occur; this situation could determine a wrong application of the technique. The accuracy of the results achievable with FAR may also be affected by a larger number of zero-count sampling units and a smaller overall sample, considered the detection effort (two visits). According to FSC (Faecal Standing Crop), the UCs are inspected only once. The FSC is measured by quantifying the number of PG present in the UC; data are subsequently converted into an estimate of the population size, using some parameters such as: the rate of defecation of the specific species and the decay rate of the PG. This technique can also be combined to the *distance sampling* technique. Usually, the measurement of the defecation rate and the rate of decay are taken from the literature, which provides fairly consistent values for each species and for each habitat. The FSC technique has some limitations, related to systematic errors coming from the difficulty of detection and classification of PG deteriorating [22], and the quantification of defecation and decay rates. Smart et al. [21] believe that the FSC is more reliable than the FAR, so much that it could be considered a valid alternative to other methods, such as the distance sampling using infrared technology; but it is important to underline how the best performances of the technique depend on the correct quantification of the decay times, habitats and specific site of pellet groups. Generally, the count of pellets groups can be considered an effective population monitoring tool. The counting of pellet groups could be the right method to combine to the classical methods of monitoring, where the data of consistency of the population produced do not allow to detect its dynamics. In this case, a survey by pellet counts every 2-5 years with an appropriate sampling effort could be sufficient to verify any changes in the population size [21]. The realization of a pilot study, however, is essential to ascertain which of the two modes of application is most suitable to the environmental context, and the to the expected goals, to get information about the ability of the technical resolution in accordance to the extent of the demographic variations that you want to detect. In this experimental work, we tried to apply one of these estimation techniques on the local wild boar population detected in an Italian Regional Park located in Benevento area (Southern Italy). The Faecal pellets Count Group was applied to a large study area of this park, in order to produce an experimental protocol, to consider as pilot study to apply in other areas.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is located in the Italian Regional Natural Park Taburno- Camposauro (Benevento -Southern Italy). This park is inside the Taburno massif (1394 m), where the surveys area for the estimate of the population of wild boar was identified. The areas of the Integral Reserve and of the General Reserve were selected as sample unit (UC), eliminating inhabited centres and anthropized areas (Fig. 1). The survey area was approximately of 2642 hectares. The habitats more representative (> 200 ha) were selected:

- chestnut woods (habitat code 9260), 218.74 ha,

- oak and turkey oak woods of (habitat code 9250), 225.11 ha,

- *mesophilous* mixed woods with alder, hornbeam, oak, maple and chestnut (habitat code 9180 *), 401.48 ha,

- mixed woods of oak, turkey oak, hornbeam and flowering ash (habitat code 9250), 258.89 ha,

- pure beech forests and holly tree (habitat code 9210*), 1236.5 ha.

2.2 Sampling Method

The choice of the monitoring-census techniques for the wild boar species (*Sus scrofa*), was decided considering the morphological differences of the territory and the Habitats characteristics. Considering these two elements it was decided to apply the Pellet Count Groups technique - Faecal Standing Crop (PCG-FSC). The chosen method was the FSC

(Faecal Standing Crop). According to this method the UCs were inspected only once. The FSC was measured by quantifying the number of Pellet Groups (PG) present in the Sample Units (CU); subsequently it was converted into an estimate of the population size, using as parameters, the specific species defecation rate and the rate of PG decay. The sampling technique was the random-opportunistic-stratified, because the goal of the sampling design was to maximize the efficiency of the process, providing the best statistical estimates with the least variability at the lowest cost [12]. Moreover, the random-opportunist technique was turned out to be the most appropriate in relation to the considerable surface of the study area, its morphology and the number of operators. The distribution of the UC sampling units (transects), was chosen according to some territorial variables in order to analyse them separately (stratified sampling by Habitat). In fact, the stratification by type of Habitat is often useful to grasp the variability deriving from the different distribution of animals according to the habitats. With a GiS software [23], it was developed an overlay to a vector file of the study area. Several layers-layers (Habitat), were included into a grid with quadrants of 400 m x 500 m (20 ha), creating 155 possible Sample Units (UC) (Fig. 1). In this way it was realised a first selection of the quadrants from the basal grid, eliminating those that do not overlap with the chosen Habitats and those falling into cultivated fields. In fact, they represent just a feeding area for the species but they are not relevant for the survey if compared to those areas that provide shelter and food, eliminating the dials of population centres. Subsequently, with an inspection on the field other quadrants were eliminated because the application of the technique was not feasible (eg. rocky walls with steep slopes). The Sampling Units (UC) chosen was constituted by strips of ground, approximately 500 meters long; the width of 1 m to the right (DX) and 1 m to the left (SX) of the midline of the transept cover an area of 1000 m2 (2 m x 500 m) (Fig. 2). The length of the transects was established by considering the environmental characteristics of the habitats and the season (winter), because the accessibility and visuality of PG on the ground are greater than in spring and summer. The starting points (start point transect) were identified through GiS. The walking direction was determined by opportunistic manner, choosing previously the direction; the accessibility of the territory was chosen as linear as possible, along 500 mt. The same procedure was used for all the transects. The starting points were chosen close to the roads available, or to treatable tracks, paths, etc. to reduce costs and efforts in applying the technique. The various data was noted on a special form modified by previous protocols suggested by the Italian Institute for Environmental Protection and Research [24]. Data included: survey card number, transept number, operator name, date, start and end times, Digitare l'equazione qui.transect length in meters, initial coordinates (Coord_SpT_E and Coord_SpT_N), weather conditions, habitat typology, number of find points pellet groups, number of faecal pellet (number of PT), distance from right and left of the midline (DX and SX), pellet status, coordinates of the find points (East and North), altitude in meters, slopes, other tracks, notes. The geographic coordinates of the starting points were inserted into the GPS. The transect was traversed by consulting the compass every 10-15 meters, to maintain the previously established direction as much as possible. The following precautions were followed in this phase [25]:

- constant speed;

- strong concentration;

- moment of pause, if tired;

- concentrate all the efforts on the central line with a procedure such as: to look in the middle, on the right, in the centre, on the left, in the centre, etc...

Faecal groups were observed only by the performer. Those casually seen by the compiler cannot be considered because the method is based on the decrease of the measurements and on the increase of the distance from the transept.

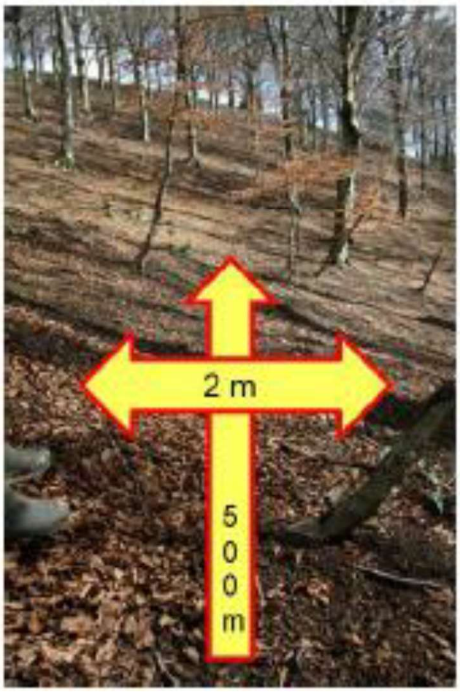
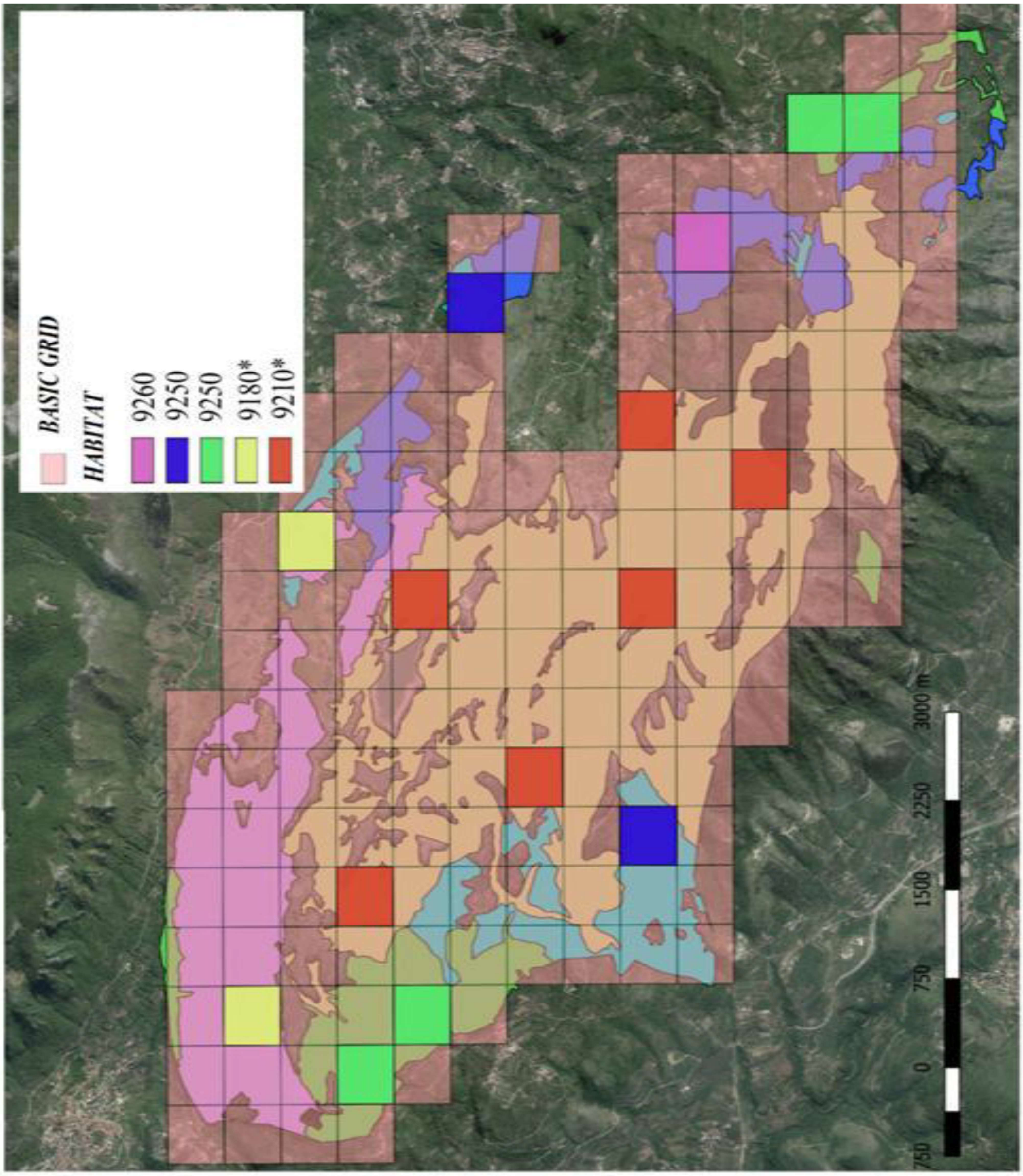


Fig. 2. Example of a transept, the arrows indicate the faecal groups

Fig. 1. Study area: quadrants are divided by Habitats, and represent the Sample Units (UC), where transepts start



Estimated density and values used in the decomposition rate and defecation rate

The formula applied to indicate density is [25]:

$$D = Npg/A \frac{Npg\ /A}{T * F}$$

D = DENSITY
Npg / A = n. Pellet Group/analysed area
T = decomposition rate
F = defecation rate

3. RESULTS AND DISCUSSION

3.1 Transects

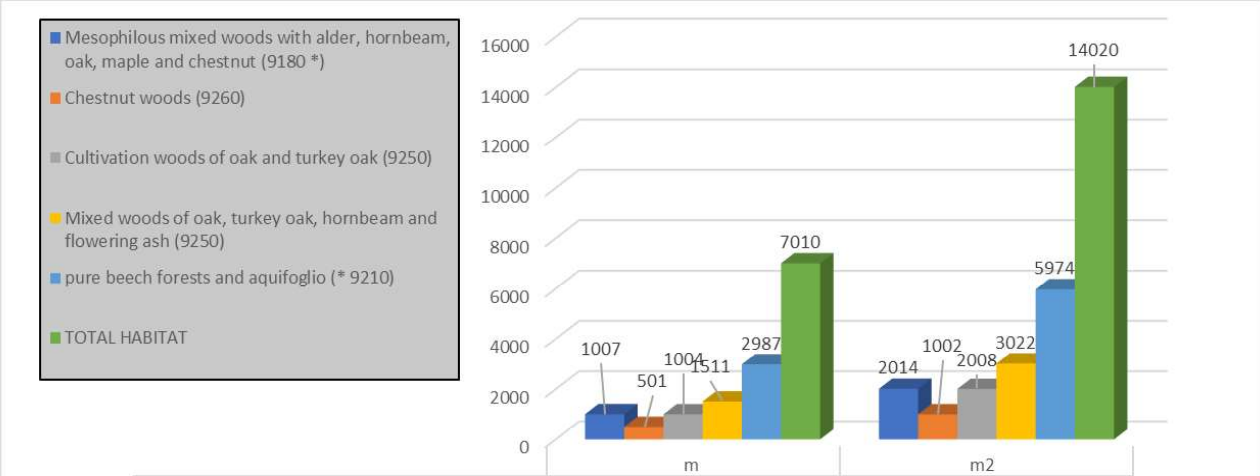
14 transects were determined in 8 days over a period of about three months (December 2016, February 2017, March 2017). 1 to 2 transect were determined every 200 ha for each habitat type, for a total length of 7010 mt and 14020 m2 (Fig. 3):

- 501 m in Chestnut woods (9260),
- 1004 m in Cultivation woods of oak and turkey oak (9250),
- 1007m in Mesophilous mixed woods with alder, hornbeam, oak, maple and chestnut (9180 *),
- 1511 m in Mixed woods of oak, turkey oak, hornbeam and flowering ash (9250),
- 2987 m Pure beech forests and holly tree (9210*).

3.2 Pellet Group and Rate Found

- The Pellet Group (PG) of the wild boar have an elongated shape of dark colour, generally depending on the feeding. These pellet groups come out from many single pellets; they over time are in most part decomposed. 12 Pellets Groups were found; they were distributed in the different habitats (Fig. 4): - 1 in Chestnut woods (9260) with a find rate of 9/ha,

- 1 in Cultivation woods of oak and turkey oak (9250) with a find rate of 4,98/ha,
- 7 in Mesophilous mixed woods with alder, hornbeam, oak, maple and chestnut (9180 *) with a find rate of 34,76/ha,
- 0 in Mixed woods of oak, turkey oak, hornbeam and flowering ash (9250)
- 3 in Pure beech forests and holly tree (9210*) with a find rate 5,02/ha.



	m	m2
Mesophilous mixed woods with alder, hornbeam, oak, maple and chestnut (9180 *)	1007	2014
Chestnut woods (9260)	501	1002
Cultivation woods of oak and turkey oak (9250)	1004	2008
Mixed woods of oak, turkey oak, hornbeam and flowering ash (9250)	1511	3022
pure beech forests and aquifoglio (* 9210)	2987	5974
TOTAL HABITAT	7010	14020

Fig. 3. Typologies of the transects analysed by habitat

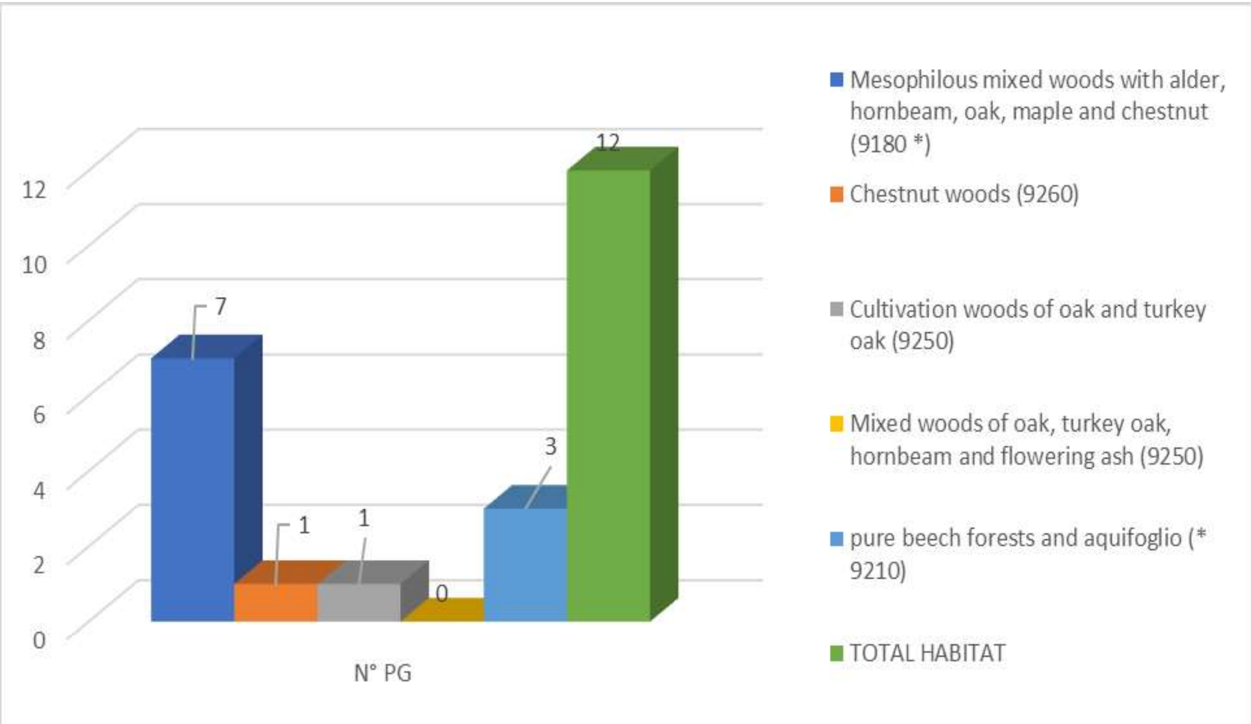


Fig. 4. Distribution of faecal groups found in the various habitats

Since it was not possible to find fresh faecal groups in the sampling areas, the average deterioration time (faecal decomposition rate) was determined applying values found in the bibliography, referred to similar characteristics of the analysed habitats. The various decomposition rates (T) used for the different typologies are: chestnut woods, 19 days; cultivation woods of oak and turkey oak, 39 days; *mesophilous* mixed woods with alder, hornbeam, oak, maple and chestnut, 46 days; pure beech forests and holly tree, 69 days [26,27]. Also, in the case of the defecation rate (F) we used two reference values [28,29], which are: 3.8 and 4.5. The results obtained by applying two different defecation rates (3.8 and 4.5, Figs. 5 and 6) show an average density of 7-8 garments per 100 ha. The values are very different from one to another depending on the wooded habitats examined.

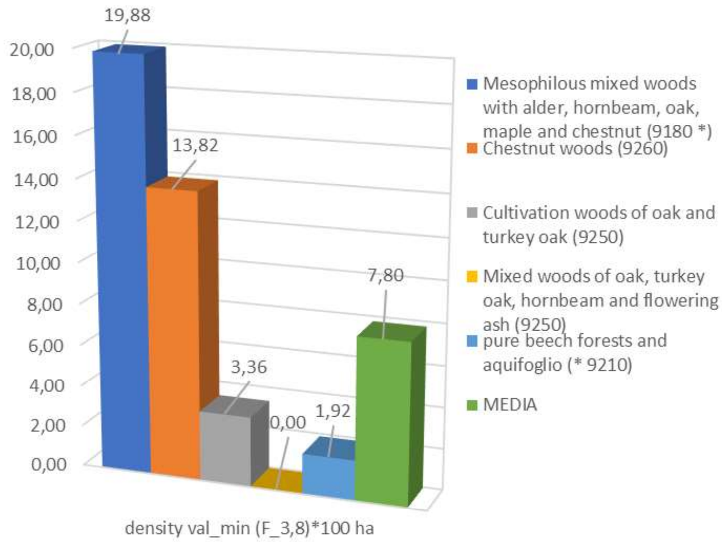


Fig. 5. Defecation rate 3,8 [28]

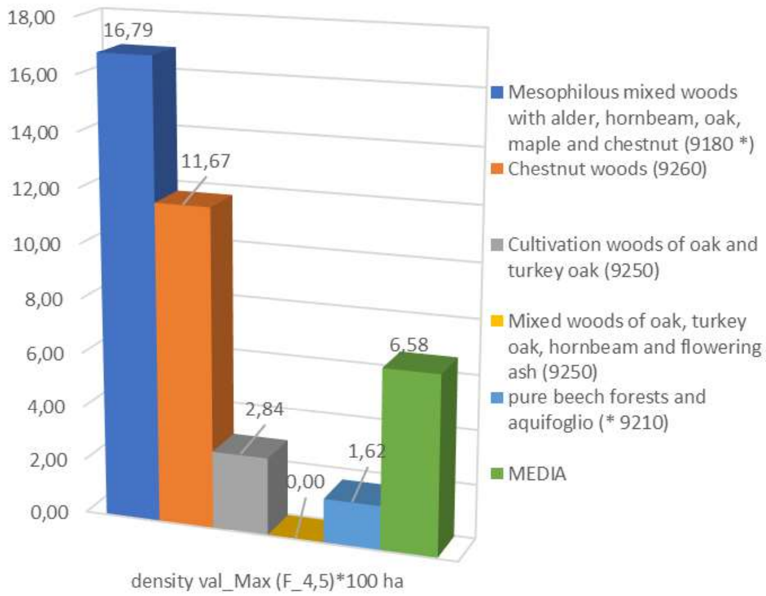


Fig. 6. Defecation rate 4,5 [29]

These results lead to the following data concerning the abundance of wild boars/100 ha in the different habitats:

- chestnut woods (9260): 12/14 heads;
- cultivation woods of oak and turkey oak (9250): about 3 heads;
- *mesophilous* mixed woods with alder, hornbeam, oak, maple and chestnut (9180 *): 17-20 *heads*;
- pure beech forests and holly tree (9210*): 2 heads.

In the case of mixed woods of oak, turkey oak, hornbeam and flowering ash no wild boars were detected. These results may have been conditioned by seasonality, environmental conditions and species behaviour. In fact, the wild boars move in the Park in the autumn-winter period, when hunting is authorized in the surrounding area. Consequently, it is in this period that they live in the Park and consider it as a shelter area. Considering all the areas together, there is an average value of 7/8 wild boars/100 ha. with considerable discrepancies between the different areas. Extrapolating the data obtained in relation to the surfaces and to the types of habitats it is possible to estimate the abundance values of the specie: the estimate of the population of wild boars ranges from 164 and 187 in the study area, applying the two indexes [28,29]. These estimates show a density much higher of the sustainable-optimal density, which is of around 47 heads (considering 2 heads/100 ha). Our census data was subsequently confirmed by harvest of the hunting bag near the park. This density should be reduced considering the relationships with other animal and plant species, and the impact on human activities. In this way it is possible to plan a balance that meets the conservation needs and reduces the damage caused to agriculture, breeding and other components of the ecosystem. To determine if the damage is tolerable or not in territory, the need for intervention must be assessed.

4. CONCLUSION

The analysis of variation of wild boars distribution, abundance and population dynamics provide essential information for managing these populations. The knowledge of the number of animals is fundamental to plan correct systems to prevent the risk of damages to the agricultural and forest environment. To determine if the damage is tolerable or not in a territory, the need for intervention must be assessed. Indeed, the same presence of wild boar in protected areas has positive aspects because they play an important role in the food chain and in the trophic cascade (large carnivores), provided that it does not exceed certain thresholds and become an ecological problem. The optimal density depends on the socio-environmental characteristics of the territory, the damage recorded and the conservationist specific needs. It is important to underline that the management of damages is not limited only to the quantitative aspects, but also to the different ways of perception of it. From a practical point of view, this problem has to be discussed and shared by all the social components involved in the management of the species, such as the comparison between the average "value" in terms of money paid for damage and prevention. So far, the sustainable planning and the objective-density parameters should not be considered as immutable values, because they refer to the principle of adaptive management and may vary over time [30,31,32,33]. This is the principle of the adaptive management. Wild Boar is one of the most difficult species to be registered, the PCG ca be adopted even in wooded environments. This survey can be considered just a pilot study in the Park area and represents a good starting point to plan a more complete census of the wild boars. This kind of survey should be repeated for several consecutive years, crossing the various data, resulting from different types of census-monitoring and increasing the intensity-effort and data bases, to get a greater reliability. In this way it will be possible to limit the error and consider population dynamics. Therefore, in addition to the work of estimating quantitatively the park populations (limit of the application of the technique of counting faecal groups), it would be essential to know the population dynamics and its distribution by age and gender, in order to keep the wild boar population under control. This means to stabilize the populations if poorly managed, keeping under control the Annual Useful Increase index (IUA), based on processes related to the birth-immigration and mortality-emigration of the species. Nevertheless, the technical parameters could be considerably affected by the policies that the park assumes. This decision should be based on the basic choices, made at the time of drafting and adoption of the Park Plan (Italian Law 6 December 1991, n. 394, Art. 12, paragraph 1, letter e), but at the same time being adaptive to the evolution of the wild boar population.

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PART IV

Behavior of Wildlife Species in Urban Areas to Changing Conditions during COVID-19 Lockdowns: A Review

Published in the journal: *Journal of Applied Animal Welfare Science*
DOI: 10.1080/10888705.2022.2047682
Published: 2022-03-02

Cite:
Nicoletta Miraglia & Aldo Di Brita (2022): Behavior of Wildlife Species in UrbanAreas to Changing Conditions during COVID-19 Lockdowns: A Review, Journal of Applied Animal Welfare Science, DOI: 10.1080/10888705.2022.2047682

ABSTRACT

The COVID-19 crisis remains an international health disaster with serious impacts on health and business. As countries asked, and continue to ask, their human populations to stay at home to limit the spread of coronavirus, wild animals have been spotted exploring the empty streets of some of the world's largest urban areas. This period of unusually reduced human mobility can provide invaluable insights into human-wildlife interactions. Reduced human mobility during the pandemic reveals critical aspects of our impact on wild animal welfare, providing important guidance on how best to share space on this crowded planet. Lockdown effects have been drastic, sudden, and widespread. Countries have also responded in broadly similar ways across large parts of the world, presenting invaluable replicates of this phenomenon. This paper will highlight various adaptations and changes in behavior developed by wild animals in urban areas during the early pandemic period. They concerned the effects on wildlife and ecosystems that are related to human activities, possible interactions between humans and wildlife, and the perspectives on wildlife and ecosystem management going forward.

KEYWORDS: COVID-19 lockdown effects; wildlife species; urban areas

1. Introduction

During the early worldwide shutdown in response to the COVID-19 pandemic, many reports evidenced that wildlife reclaimed cities. The consequences of reduced human mobility due to confinement led to less traffic and consequently lower pollution levels including noise and chemical emissions. The noise reduction led to movement of wildlife and shifts in habitat use (Bates, Primack, Moraga, & Duarte, 2020). It is unclear whether wildlife truly reoccupied urban areas or if this phenomenon was simply linked to this time. It is of great interest to investigate the responses of wildlife to changes in human activities. During the pandemic, people have been given the opportunity to gain unanticipated insight into how their presence affects animal behavior and how quickly and flexibly animals can react to unprecedented changes, such as lockdowns and the "global human confinement experiment" (Bates et al., 2020). Additionally, COVID-19 lockdowns increased public interest in urban nature (Roll, Jepson, Jaric, & Ramos Pinheiro, 2021). As more countries asked their human populations to stay at home to limit the spread of COVID-19, wild animals explored the empty streets of some of the world's largest urban areas (Derryberry, Phillips, Derryberry, Blum, & Luther, 2020; Zellmer et al., 2020a). Interestingly, the response of wildlife to changes in the functioning of human society and economy was also rapid. The reduction in human disturbance allowed wildlife to exploit broader habitat areas and to increase daily activity; the coronavirus pandemic has given wildlife more room to play in urban areas (Liu, Ma, Zheng, Si, & Cadotte, 2020). Human activities have recently been defined as an "anthropause" (Rutz et al., 2020). The anthropause refer specifically to a considerable global slowing of modern human activities, notably travel. The impacts of reduction of human activities are not limited changes in emissions; worldwide newspapers and social media started to pop up posts and news about unprecedented wildlife sightings in urban areas (Rutz et al., 2020), often claiming that "nature just regains its space" (The Economist, 2020). From the beginning of the pandemic, evidence of the presence of wild animal species in areas where they have long been absent were shared on social media. Early in the shutdown, images of wildlife in cities were common, increasing public attention and declarations of wildlife reclaiming urban habitats (Sahagun, 2020). Despite some positive effects, lockdowns favored the spread of alien or problematic species and highlighted several negative impacts of the COVID-19 crisis on wildlife. Well-established alien species becoming more active during lockdown comprised 14% of the increased wildlife activity (Lo Parrino, Falaschi, Manenti, & Ficetola, 2021; Manenti et al., 2020). A number of various changes in animal behavior were also observed, including increased aggression, changes in feeding sites, and the formation of new competitive systems in synanthropic species suddenly deprived of anthropogenic food. This article describes different situations developed by wild animals in urban areas during the early pandemic period, possible interactions between humans and wildlife, and perspectives on these situations for animal welfare and management. Data was obtained from academic articles which appeared in the period 2020–2021 concerning the effects on wildlife and ecosystems due to the anthropause. Anecdotal data of wildlife incursions into urban areas are also reported.

2. COVID-19 shutdown and changes in wildlife behavior

During the anthropause, a number of various changes in animal behavior were observed, including changes in birds' vocalizations, increased aggression, changes in feeding sites, and the formation of new competitive systems in synanthropic species suddenly deprived of anthropogenic food. During the early pandemic period, humans were given the opportunity to gain unanticipated insight into how their presence affected animal behavior and how quickly and flexibly animals can react to unprecedented changes, within this "global human confinement experiment" (Bates et al., 2020). Interestingly, the response of wildlife to changes in the functioning of human society and economy was also rapid. The reduction in human disturbance allowed wildlife to exploit and increase their daily activity within urban habitats. This flexibility in behavior shows that many animals can quickly respond to changing conditions, including the absence of humans. During the anthropause, many reports emerged of urban wildlife sightings. As humans retreated into their homes as more and more countries locked down, wild animals slipped cover to explore the empty streets of some of the world's biggest cities. Most of the published pandemic–wildlife papers focused on changes in the movement and behavior of wild animals. These show how the daily presence of humans may limit the presence and behavior of animals. Researchers assessed the effects of the anthropause using multiple tools (analysis of media news, field records and questionnaires sent to managers of protected areas). Many of these tools are not quantitative and consequently it is quite hard to verify the real effect of lockdown. There are some species like some birds and mammals of which quantitative field data are available (Basile et al. 2021; Manenti et al., 2020). This is the case of crested porcupine Hystrix cristata observed in March–April between the years 2011–2019 and 2020 throughout Italy, (Manenti et al., 2020). Changes in the demographic and genetic characteristics of the population of hedgehogs were observed in Europe and the effect was that it was stopped the long-term decline in their number (Łopucki, Kitowski, Perli ´nska-teresiak, & Klich, 2021). Additionally, road mortality rates of animals during the lockdown were down by over 50% lower compared with the pre-pandemic years (Nguyen, Saleh, & Kyaw, 2020). Urban animals have been able to adapt to our landscape and live alongside towns, cities and suburbs so we know they are already highly adaptable. COVID-19 lockdowns and travel restrictions also changed the behavior of many wild animals (Corlett et al., 2020; Gaynor et al., 2020; Vardi, Berger-Tal, & Roll, 2021).

3. Wildlife in urban areas

During the early lockdown months of 2020, hundreds of media reports described species sighted in unusual places around the world. They were based on 877 qualitative reports and 332 quantitative assessments (Bates et al., 2021). Perhaps the most important phenomenon was the human recognition of our place in the natural world – people locked up in their homes realized how much they missed nature (Bates et al., 2021). Some examples concerning different situations all over the globe will highlight this phenomenon. In Europe, wild boars have descended from the hills around the Catalan city of Barcelona (Sharma, Kaur, & Narwal, 2020). The presence of wild boar in urban areas was observed also in many Italian towns (*La* Stampa, 2021). Ducks were seen walking quietly near the Comédie Française theatre in central Paris (France24, 2020). The European roe deer, endemic to the Tatara Mountains straddling Poland and Slovakia, were seen more freely roaming towns and cities they previously avoided. Fallow deer from Dagnam Park were observed roaming near Romford, England (Chalasani, 2020). These semi-urban deer are a regular sight in the area around the park, but as the roads became quieter due to the nationwide lockdown, the deer appeared to stake a claim on new territories in the vicinity. Mountain goats who live on the rocky Great Orme in Wales are usually only occasional visitors to the seaside town of Llandudno. Kashmir goats have lived on the Great Orme promontory near Llandudno since the days of Queen Victoria, when the species became popular in Britain due to a fashion for shawls made from their soft cashmere wool. These Kashmir goats invaded the Welsh seaside resort after the coronavirus lockdown left the streets deserted (BBC, 2020; RFI, 2020). The animals, which normally live about the village on a headland jutting out into the Irish sea, moved into the village and spent their days in the gardens around the town.

The anthropause benefits for marine mammals can be attributed to reduced ship traffic during COVID-19 lockdowns (Rutz et al., 2020; Times of India., 2020). In the Mediterranean, dolphins reappeared in several ports; in the waters of the Bosphorus, dolphins swam near the shoreline in Turkey's largest city Istanbul. In Florida, the Loggerhead Marinelife Center reported an increase in leatherback turtles in 2020. The turtles have been bigger and healthier. And endangered turtles seem to nest in greater numbers along beaches suddenly empty of tourists. Thailand reported 11 leatherback turtle nesting sites since November, the largest increase in two decades.

In the United States, variation in urban wildlife and urban environments were observed by urban ecologists and often reported by media (CNN, 2020; The Economist, 2020; The Guardian, 2020a, 2020b; The Telegraph, 2020; Zellmer et al., 2020a). Coyote (*Canis latrans*) were observed on Los Angeles sidewalks, for weeks in the spring, coyotes were spotted on San Francisco's empty streets, with at least one near the Golden Gate Bridge. The western fence lizard (*Sceloporus occidentalis*) was observed in microhabitats in California; the red admiral butterfly (*Vanessa atalanta*) was noted on a purple coneflower (*Echinacea purpurea)* in Chicago, Illinois; Gambel's quail (*Callipepla gambelii*), were seen in Arizona; gangs of wild turkeys strutted in the streets of Oakland, California; and raccoons, prominent in urban areas, are being spotted more frequently. Many racoons were observed walking in almost deserted Central Park, New York City.

In India the Yamuna River saw a visible reduction in pollution since India's COVID-19 lockdown began. Hundreds of monkeys have taken over streets around the Indian president's palace during the country's lockdown. Flamingos were seen in huge numbers in Talawe wetland during India's nationwide lockdown, (Mumbai, April 2020). The Bombay Natural History Society estimated that the number of flamingos is 25% more than in 2019 in the Talawe wetlands and other areas of Mumbai, India. The lockdown meant a lack of human interference in their obtaining food and roosting. In India noise reduction and less human activity seemed to benefit birds, who extended their stays (The Hindu, 2020). Resident birds bred much more than before due to less human activity, no noise and air pollution (India New England, 2020; India Today, 2020).

In Chile a wild puma was captured after it was found wandering around the deserted centre of Santiago in search of food in March 2020 (Sharma et al., 2020). The puma came down to the capital city from nearby surrounding hills. In Peru thousands of birds flocked to Agua Dulce beach, then largely absent of beachgoers in March, 2020. The birds began swarming the empty shores following Peru's president declaration of a state emergency which ordered people to stay home. Penguins also roamed the streets of eerily quiet South African towns (Sharma et al., 2020).

It is important to note that the long-documented presence of wildlife in cities brings into question whether the reported wildlife sightings during the COVID-19 shutdown are in fact indicative of a change in wildlife behavior, or of humans noticing that behavior. Scientists and citizens have long-documented wildlife in cities, including mammals, insects, and other invertebrates, birds, and herpetofauna. Regardless, this period of unusually reduced human mobility provided invaluable insights into wildlife behavior.

Negative effects of the lockdown on conservation also emerged concerning mainly illegal activities such as hunting (Buckley, 2020) and the risks of negative conservation effects coming from reduced tourism. The presence of humans and their activities have a considerable impact on food availability for animals within both land and marine habitats, including that of top predators and scavengers. The role of human-sourced food is an important driver of wildlife occurrence, condition, and thus welfare (Bates et al., 2020). Empty streets and the absence of people made some animals bolder, while animals normally dependent on tourists were deprived of this food source (Newsome, 2020). In some instances, local street dogs, cats, monkeys, crows and free birds depend upon foods from tourists. During lockdown, many of these animals were in crisis for food, sometimes fighting with each other in the process. The roaming of the wild animals in residential areas in these instances may be due to these food shortages (Bar, 2020). COVID-19 put a sudden stop to tourism, giving some animals unprecedented freedom. However, between decades of habitat loss and a diminishment in food, other animals that are dependent on humans aren't benefiting as much. While some animals adapt and survive despite the circumstances, many depend on human intervention: a majority of animal survival depends heavily on humans. While a break in tourism can help regenerate natural environments and give animals the opportunity to reestablish breeding and feeding practices, too long of a hiatus can be detrimental (Rowe, 2020). These changes, although interesting, may be ephemeral and may not have any significant effect on wildlife in the long run.

4. Environmental variables related to COVID-19

The impact of human confinement in lockdown on the atmospheric environment and its effect on the welfare of animals in their respective ecosystems offers an opportunity to assess the degree of environmental degradation that normal human civilization causes. The behavioral changes of wild animals, birds, butterflies, and companion and street animals during lockdowns indicate how much human activity interferes with wild animal's lives and welfare. The COVID-19 crisis remains an international health disaster with serious impacts on health and business. Still, COVID-19 lockdowns enhanced air quality by reducing carbon emissions which led to enhanced environmental health (Rupani et al., 2020). Globally, 210 countries invoked quarantines with various degrees of strictness to face COVID-19 (Bates et al., 2021). India and China applied strict and quick restrictions to manage the pandemic and decrease death rates. Because of this, NO2 and CO2 pollution dramatically declined in many cities across the globe (Paital, 2020), causing a reduction of 7% in total carbon emission at end of 2020. In the lockdown period, the level of NO and carbon emissions decreased in the atmosphere due to restricted consumption of fossil fuel by industries, thermal power stations, and transportation. Less traffic and construction activities also lowered intensity of particulate matters like PM2.5 and PM10, which decreased by 43% and 31%, respectively.

Carbon dioxide (CO2) emissions are responsible for the climate change. The transportation sector, industries, and electrical generation contribute to CO2 emissions. Due to coronavirus lockdowns, emissions of CO2 decreased worldwide (NASA-National Aeronautics and Space Administration, 2020), and experts predicted this to be the biggest decline in anthropogenic CO2 emissions since World War-II. I. (Khan, Shah, & Shah, 2020). Total lockdown in many countries saw a halt in carbon-and energy-intensive economic sectors such as manufacturing and transportation. It was reported that the social distancing measures led to a decline of energy demand and industrial output, hence affecting environmental quality. Additionally, the interruption of road transportation and airline flights cause both decongestion in urban centres and le to a decline in anthropogenic emissions (Kerimray et al., 2020). The reductions in air and water pollution were noticeably recognized in many regions like France, Italy, Los Angeles, Spain, and Wuhan city of China (Bar, 2020).

In 2020 many researchers wondered if the extent of the favourable influences on carbon emission would remain, as soon as the travel restrictions are released (El Zowalaty, Young, & Järhult, 2020), with some researchers noting the significance of continuing these environmental advantages through air pollution reduction rules (Bar, 2020). The anthropause provided a glance of what the planet might be like without fossil energy sources and hope that people could exit this pandemic with a healthier, cleaner globe. This could happen if a long-lasting mind-set were adopted by institutions, communities, and individuals, followed by restricted regulations and policies to stop anthropogenic environmental deterioration (Rupani et al., 2020). It was also suggested that post-COVID-19 could slow down human dominancy and environmental damage and that the self-refreshed environment, with less human interference could become permanent with awareness brought about by the anthropause (You et al., 2020). COVID-19 recovery programs could lay the foundation for a more sustainable future for humans and animals. Researchers argued that nations should not squander this opportunity (Rosenbloom & Markard, 2020).

Nevertheless, the climate conference held in Glagow in November 2021 showed that the reduction in the emission of CO2 during pandemic period could be considered ephemeral. Climate-related risks to health, livelihoods, food security, water supply – all affecting animals as well as humans – are projected to increase with global warming of 1.5°C and increase further with 2°C. The Intergovernmental Panel on Climate Change (IPCC, 2021) notes that such an increase, unless changed quickly, may lead to a temperature rise of about 2.7°C by the end of the century. This situation implies that 6% of insects, 8% of plants and 4% of vertebrates are projected to lose over half of their climatically determined geographic range for global warming of 1.5°C, compared with 18% of insects, 16% of plants and 8% of vertebrates for global warming of 2°C. Impacts associated with other biodiversity-related risks such as forest fires and the spread of invasive species are also lower at 1.5°C compared to 2°C of global warming (IPCC, 2021; Warren, Price, Graham, Forstenhaeusler, & Vanderwal, 2018).

5. Conclusions

Reduced human mobility during the pandemic revealed critical aspects of human impacts on animals, providing important guidance on how best to share space on this crowded planet. The behavioral changes of wild animals, birds, butterflies, and companion and street animals during the anthropause indicate the degree of interference of human activities on lives of many animals. The lockdown's impact on wildlife expansion into human spaces involved a reduction of noise, presence, and air/water pollution, the reduction of transportation of invasive species (positive for native species and ecosystems); and there was a certain effect of border closure (mostly negative effect on transboundary species) (Bates et al., 2021). Many of the habitat expansion-related behavioral responses observed may be transient. For example, animals roaming in areas typically supporting intense human activity may retreat back to smaller ranges once human activity resumes full scale (Bates et al., 2021).

The COVID-19 lockdown is an unplanned experiment of how stopping or limiting human activities can affect wildlife (Bates et al., 2020; Rutz et al., 2020). In most cases, biodiversity has benefited from reduced human activities (Corlett et al., 2020). Also, there was a certain correlation between atmospheric changes with the behavioral changes of wild animals during lockdown periods. The recognition of the degree of anthropogenic environmental devastation brought about by its reduction during the anthropause may have resulted in the realization for many that modern life could be carried on without harming the environment dramatically. COVID-19 can enhance the air quality by reducing carbon emissions which will lead to enhanced environmental health (Rupani et al., 2020), benefitting all animals. The recovery of lost environment during the anhtropause is an indicator that the environmental degradation caused by humans is reversible (Khan et al., 2020). It is not clear yet to what extent the favourable influences brought about by the lockdowns will remain (El Zowalaty et al., 2020), but there is the hope that the impact of COVID-19 will increase people’s awareness of the environmental issues (Rupani et al., 2020). Preserving the processes that sustain the functioning of the biosphere (Manenti et al., 2020) represents a key priority for governments worldwide.

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GENERAL CONCLUSIONS AND FUTURE PERSPECTIVES

The value and the circular capacity of wildlife management have long been recognized for the protection of habitats and species, as well as the mitigation of the impacts that native and / or alien wild animals can cause to anthropic activities and competitions in which they live. Adaptive wildlife management is the keystone to an approach with strong scientific bases, indications that the IUCN itself (International Union for Conservation of Nature) repeats the concepts in every document and context. The success of this approach is based on conservation principles, that is to act with actions indicated by variables of contexts in which one operates and scientific data that are continuously evolving, to ensure that future generations can take advantage of the same "resources" over time, that our own generation uses it today, for example sensitive species, in decline or with an unfavorable state of conservation. Since in the context of adaptive wildlife management the management choices depend on the results of the monitoring, but above all on the data available, it is obvious the need for adequate information collection, which makes use of a correct sampling strategy and concerns a sample quantitatively and qualitatively. representative. Similarly, the subsequent phase of interpreting the collected data requires a rigorous approach, capable of highlighting the critical points and avoiding forced interpretations. A fundamental piece is a continuous collaboration between the scientific world, specialist associations, universities and research, government bodies and public citizens. In this regard, today new technologies allow to simplify, increase and develop technical supports and models for adaptive management. In fact, the use of GIS software are a tool to support decisions, tools that, implemented by databases, can facilitate the political and technical decision-maker in the choice of actions, calibrating them according to real situations and verifying in the presence of historical data, the effects related to problems to every context. In this regard, the overall research activity carried out during the doctoral period made it possible to initiate some studies related to the management of wild boar in the Molise context and in support of the same. In particular, the study focused on the development of spatial-environmental map models useful for decisions. In particular, the creation of the impact map of the wild boar of the Molise Region and the map of the ecological corridors of the city of Campobasso can support the management of the species in the context in which they were created, identifying areas with greater urgency for effective action. Actions also related to the operating legislative context and concentrate efforts, resources and management means in those places. This is functional to the current context, because the current public administrations are experiencing a time of economic and staff personell scarcity and are increasingly finding themselves dealing with these further problems. The geo-referenced damage of wild boars demonstrates how almost all the damages are concentrated in the areas where road accidents have occurred and where there is the maximum risk of impact. The impact maps of the ungulates are fundamental tools to define the non-suitable / problematic areas mainly in the case of non-conservative management of the species, especially where the Human-wildlife conflict is more evident. These studies could be improved by identifying the portions of the territory where to carry out the control operations pursuant to art. 19 L.N. 157/92. These areas should be managed through control interventions, adequate local studies of territorial analyses and different methodologies for fauna management and biological analysis of the species. The value and the circular capacity of wildlife management have long been recognized for the protection of habitats and species, as well as the mitigation of the impacts that native and / or alien wild animals can cause to anthropic activities and competitions in which they live. Adaptive wildlife management is the keystone to an approach with strong scientific bases, indications that the IUCN itself (International Union for Conservation of Nature) repeats the concepts in every document and context. The success of this approach is based on conservation principles, where different actions are constituted by variables and scientific data that are continuously evolving. In this way it will be possible to ensure that future generations can take advantage of the same "resources" over time. In the context of the adaptive wildlife situation the management choices depend on the results of the monitoring, but it is evident the need of adequate information data, which makes use of a correct sampling strategy and concerns representative samples both quantitatively and qualitatively. Similarly, the subsequent phase of interpreting the collected data requires a rigorous approach, capable of highlighting the critical points avoiding forced interpretations. A fundamental aspect is the continuous collaboration between the scientific world, specialist associations, universities and researchers, government bodies and public citizens. Today the new technologies allow to simplify, increase and develop technical supports and models for adaptive management. In fact, the use of GIS software is a good tool to support decisions; in this way it is possible to implement the databases and consequently to facilitate the political and technical decision-makers to choose correct actions, calibrating them according to real situations. The evaluation of historical data will agree to verify the present situation to every context. In this regard, the overall research activity carried out during the doctoral period made it possible to initiate some studies related to the management of wild boar in the Molise context and in support of the same. In particular, the study focused on the development of spatial-environmental map models useful for decisions. The creation of the impact map of the wild boar of the Molise Region and the map of the ecological corridors of the city of Campobasso can support the management of the species in the context in which they were created, identifying areas with greater urgency for effective actions. Actions also related to the operating legislative context and concentrate efforts, resources and management means in those places. This is functional to the present context, because the current public administrations need more and more knowledge concerning the wild boars containment. The study of the density of wild boar in the Taburno Camposauro Regional Park represents a good starting point for the decisions of the administration of the Authority and the territory, indicating at least the minimum indicative population present in that area. The values of these tools created to support wild boars management can be summarized as follows:

1) Identify the real situation based on spatial data;

2) Create a historical database and understand its evolution over time;

3) Define immediate action on the territories with species-specific actions;

4) Develop management forecasting models based on the element's evolution of the territory;

5) To study the biological and trophic characters of the species, implementing the ethological knowledge of the species.

The analysis of variation of wild boars distribution, abundance and population dynamics provide essential information for managing these populations. The knowledge of the number of animals is fundamental to plan correct systems to prevent the risk of damages to the agricultural and forest environment. To determine if the damage is tolerable or not in a territory, the need for intervention must be assessed. It would be essential to know the population dynamics and its distribution by age and gender, in order to keep the wild boar population under control. This means to stabilize the populations if poorly managed, keeping under control the Annual Useful Increase index (IUA), based on processes related to the birth-immigration and mortality-emigration of the species. In this regard, the next step will be to start studies of new models also using the *Citizen Size*, as it is impossible to think that technological tools alone can show us the way to go without interacting and being supported by information from citizens who live in places and problems. For example, obtaining information from custodian citizens who live in rural areas and know local fauna habits and local dynamics, in real time. This information is a real asset, their knowledge, transoping it and integrating it with a scientific method and recording it with technologies such as apps for mobile phones and the use of drones, in order to increasingly implement the data in support of these spatial models and create others that are increasingly incisive and pedestal in decision-making choices, choices made with scientific criteria and not empathic ones.