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**Tesi di laurea specialistica in Forest and Environmental
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*NDVI and daily movements of Alpine ibex (*Capra ibex ibex*, Linnaeus
1758) females*

Relazioni tra NDVI e movimenti giornalieri di femmine di stambecco delle Alpi (*Capra ibex
ibex*, Linnaeus 1758)

Relatore: Prof. Maurizio Ramanzin

Correlatore: Dott. Francesco Pirotti

Laureando: Marco Dubbini

Matricola n. 1057499

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Abstract

The effective management of any species passes through an acquisition of good scientific knowledge of its history, ecology and of the area where this management will act.

This thesis deals with the interactions between the daily movements of a group of Alpine ibex (*Capra ibex ibex*, Linnaeus 1758) females and the Normalized Difference Vegetation Index (NDVI), a vegetation index used as a proxy of the vegetation quality. I have used satellite maps from USGS and the GPS positions of the animals to calculate the NDVI of the area and the NDVI of the animals positions. In order to make a comparison I have created random points, located in a buffer zone around the real position, and calculated random values of NDVI inside this buffer.

The results show that there are only minor differences between the NDVI values associated with the animals positions and those associated with random points. But, due the fact that many maps have low NDVI values that can be related to the presence of rock or snow in the pixel, I decided to compare the land covers use with the availability. Also in this case the results suggest that there is no selection for any land cover class, but also in this case I have seen that the highest values of use and availability are for classes with low presence of vegetation.

Therefore, I analyzed NDVI values only for the land cover classes with vegetation, even if this operation decreased my sample size. The results suggest that there is less use than availability in class of NDVI between 0-0,2, while there is a positive selection in class of NDVI between 0,2-0,4.

These results must be confirmed by further studies with a larger samples size, but they show that, when vegetated land cover areas are considered, it is possible to find a positive relationship between the NDVI and the selection of patches by the Alpine ibex.

1. Introduction

This thesis will analyze the use of vegetation indexes in order to discover some of the behavior aspects of the Alpine ibex. This species has a peculiar history and ecological features, as we will explain better in next chapters.

Until the recent past, the management of wildlife has been mainly guided by commonsense or tradition (Sutherland et al., 2004) and it is easy to understand that, instead, the support of research is necessary during the decision making process, also because the management actions are often taken in complex situations, where it is very important to have a deep knowledge of the entities involved (Scillitani et al., 2012).

In the next chapters I will explain the state of art of the vegetation indexes in research purpose and why I have chosen the Normalized Difference Vegetation Index; I will also briefly describe the present status of Alpine ibex in Alps and his main characteristics. I will then explain the objectives of this study.



Fig. 1.1: Marmolada view with Alpine ibex males (<http://www.belledolomiti.it>, 2014)

1.1 Remote Sensing

When speaking about Vegetation indexes, it is important to underline how to collect the data in order to discover the results.

Remote sensing in fact is the means through which we can take this information. I can define it as the action of measuring properties of an object at a certain distance, for this reason it is so important and useful, because I am able to collect data also if we are far away from our object of interest, that can be for example something located in an area with a difficult access. Since the satellite is not near the object, we need propagated signals in order to take the data, that can be optical, acoustical or microwave. I can make a distinction between passive sensors that take data from natural radiation emitted or reflected by the object or the area that we are analyzing or active collection where, in order to collect the information, there is the emission of radiation that is reflect by our target.

The history of remote sensing starts with the development of flight, in fact already in the 1858 there was the first aerial photograph of Paris. But just from the first world war the aerial photography became to be systematically used until the cold war. The later step of the remote sensing start with the development of artificial satellites, that put it from a local to a global scale and allow the transition from military purpose to also civil and research aims.

Nowadays some of the most important applications of remote sensing are:

- Military surveillance.
- Environmental assessment and monitoring.
- Agriculture such as crop condition or soil erosion.
- Exploration of new resource such as minerals.
- Meteorology.
- Mapping.
- Global change detection and monitoring.

The modern era of earth remote sensing from satellites began with launch of the Landsat Multispectral Scanner System (MSS) in the 1972. The innovation came from the multiple

spectral bands that allows to receive data about different region of the electromagnetic spectrum and moreover in a large area and repeating coverage.

The most recent, Landsat 8, was launched on February 11, 2013. The instruments on the Landsat satellites have acquired millions of images.

The images, archived in the United States and at Landsat receiving stations around the world, are a unique resource for global change research and applications in agriculture, cartography, geology, forestry, regional planning, surveillance and education, it can be viewed through the USGS "EarthExplorer" website. Landsat 7 data has eight spectral bands with spatial resolutions ranging from 15 to 60 meters; the temporal resolution is 16 days. Landsat 8 instead has got more bands used for closer investigations of coastal areas and estimating the concentration of aerosols in the atmosphere and for a better detection of cirrus cloud contamination.

1.1.1 Vegetation indexes

Vegetation Indexes (Vis) are combinations of surface reflectance at two or more wavelengths designed to highlight a particular property of vegetation. They are derived using the reflectance properties of vegetation and their primary aim is to characterize the type, amount and condition of vegetation present in an area. They are widely used and affect a lot of disciplines interested in the assessment of biomass, plant stress, plant health, crop production and water use (Huete et al., 1997).

More than 150 VIs have been published in the scientific literature, but only a small subset have a substantial biophysical basis, or have been systematically tested. The indices are grouped into categories that calculate similar properties (www.exelisvis.com, 2014):

- Broadband Greenness.
- Narrowband greenness.
- Light Use efficiency.
- Dry or senescent carbon.
- Leaf pigments.
- Canopy water content.

Each category of indices typically provides multiple techniques to estimate the absence or presence of a single vegetation property, for different properties and field conditions, some indices within a category provide results with higher validity than others.

The broadband greenness Vis are based on the reflectance measurements that depend on the foliage chlorophyll concentration such as canopy leaf area and foliage clumping. These VIs are designed to provide a measure of the overall amount and quality of photosynthetic material in vegetation, which is essential for understanding the state of vegetation for any purpose. They do not provide quantitative information on any one biological or environmental factor contributing to the fAPAR (fractional quantitative absorption of photosynthetically active radiation), but broad correlations have been found between the broadband greenness VIs and canopy LAI. All these indexes are based on the comparison of the reflectance of the near-infrared with another measurement taken in the range of red.

They are used mostly in the assessment of vegetation phenology growth, its modeling and land use and climatological impacts. They are:

- Normalized Difference Vegetation Index: Normalized difference of green leaf scattering in near-infrared, chlorophyll absorption in RED (Sellers, 1985).
- Simple Ratio Index: Ratio of green leaf scattering in near-infrared, chlorophyll absorption in RED (Sellers, 1985).
- Enhanced Vegetation Index: An enhancement on the NDVI to better account for soil background and atmospheric aerosol effects (Huete et al., 1997).
- Atmospherically Resistant Vegetation Index: An enhancement of the NDVI to better account for atmospheric scattering (Kaufman et al., 1997).
- Sum Green Index: Integral of scattered light in the GREEN spectral range is sensitive to gaps in vegetation canopy (Lobell et al., 1997).

Narrowband greenness Vis are similar to broadband greenness Vis, but the former are designed to provide measurements of general quantity and quality of green vegetation, while the latter usually provide a broader information. In fact, narrowband Vis use bands of the near infrared but also bands in the edge of red (from 690 to 740 nm), this particulars make a difference in order to get information about small changes in vegetation health. However, they need high spectral resolution imaging data. Narrowband Vis are:

- Red edge Normalized Difference Vegetation Index: A modification of the NDVI using reflectance measurements along the red edge (Sims & Gamon, 2002).
- Modified Red Edge Simple Ratio Index: A ratio of reflectance along the red edge with blue reflection correction (Sims & Gamon, 2002).
- Modified Red Edge Normalized Difference Vegetation Index: A modification of the Red Edge NDVI using blue to compensate for scattered light (Datt, 1999).
- Vogelmann Red Edge Index 1: A shoulder of the RED-to-NIR transition that is indicative of canopy stress (Vogelmann et al., 1993).
- Vogelmann Red Edge Index 2: A shape of the near-infrared transition that is indicative of the onset of canopy stress and senescence (Vogelmann et al., 1993).
- Red Edge Position index: The location of the maximum derivative in near-infrared transition, which is sensitive to chlorophyll concentration (Curran et al., 1995).

The light use efficiency Vis differ from the greenness Vis because they provide a measure of the efficiency of vegetation in using incident light, which allows to estimate growth rate and production that can help in agriculture. The light use efficiency Vis use reflectance of the visible spectrum and are:

- Photochemical Reflectance Index: Used to estimate absorption by leaf carotenoids (especially xanthophyll) pigments, leaf stress, and carbon dioxide uptake (Gamon et al., 1997).
- Structure Insensitive Pigment Index: Indicator of leaf pigment concentrations normalized for variations in overall canopy structure and foliage content (Penuelas et al., 1995).
- Red Green Ratio Index: Ratio of reflectance in RED-to-GREEN sensitive to ratio of anthocyanin to chlorophyll (Gamon & Surfus, 1999).

The canopy nitrogen VI include actually only one index, the Normalized Difference Nitrogen Index, which aims to provide a measurement of the nitrogen concentration. Nitrogen is highly present in chlorophyll and moreover is present in high concentrations when plants are growing fast. It uses reflectance in the shortwave infrared range (Serrano et al., 2002).

The dry or senescent carbon Vis want to give estimation of the quantity of carbon in dry states of lignin and cellulose. Carbon is used by the plants for the synthesis of structural components, and dry carbon is mostly present in wood and dead or senescent vegetation, all materials very flammable. That's why dry carbon Vis can be used for the fire analysis risk of an area. They use reflectance of the shortwave infrared range and they are:

- Normalized Difference Lignin Index: Detects leaf lignin increases at the 1754 nm feature relative to 1680 nm canopy structure region (Melillo et al., 1982).
- Cellulose Absorption Index: Detects absorption features due to cellulose above 2000 nm (Daughtry, 2001).
- Plant Senescence Reflectance Index: Uses a ratio of carotenoids to chlorophyll to detect onset and degree of plant senescence (Merzlyak et al., 1999).

The leaf pigment Vis are useful for the measurements of the presence of carotenoids and anthocyanins, pigments that are present in high concentrations in weakened plants. They can be used to monitor crop health such as canopy stress and in general for ecosystem studies. They use reflectance in the visible spectrum and are:

- Carotenoid Reflectance Index 1: Detects a relative difference in absorption indicative of changes in leaf total carotenoid concentration relative to chlorophyll concentration (Anatoly A Gitelson et al., 2002).
- Carotenoid Reflectance Index 2: Similar to CRI1, but uses a different wavelength to estimate the chlorophyll content (Anatoly A Gitelson et al., 2002).
- Anthocyanin Reflectance 1: Changes in GREEN absorption relative to RED indicate leaf anthocyanins (A A Gitelson et al., 2001).
- Anthocyanin Reflectance 2: A variant of the ARI1, which is sensitive to changes in GREEN absorption relative to RED, indicating leaf anthocyanins (A A Gitelson et al., 2001).

The canopy water content Vis measure the amount of water in the leaves of the canopy, which can be a proxy of vegetation's health and resistance to fire. They are measured with the reflectance in the near infrared and shortwave infrared regions, and are:

- Water Band Index: Absorption intensity at 900 nm increases with canopy water content (PEÑUELAS et al., 1993).
- Normalized Difference Water Index: The rate of increase at 857 nm absorption relative to 1241 nm is a direct metric of total volumetric water content of vegetation (Gao, 1996).
- Moisture Stress Index: Detects changes at 1599 nm absorption that is sensitive to the onset of moisture stress in vegetation (Hunt & Rock, 1989).
- Normalized Difference Infrared Index: Absorption intensity at 1649 nm increases with canopy water content (Jackson et al., 2004).

In this thesis we are going to focus on the use of the NDVI (normalized difference vegetation index) that belongs to the group of the broadband greenness Vis.

1.1.2 Normalized Difference Vegetation Index

Before choosing the NDVI we have tested other 3 possible indexes, an index of greenness, an index of wetness and an index of brightness. They refer to the tasseled cap transformation, a conversion of the original band of the satellite map in to a new set of bands that can be useful when looking for vegetation features. The first tasseled-cap band corresponds to the overall brightness of the image. The second tasseled-cap band corresponds to “greenness” and is typically used as an index of photosynthetically-active vegetation. The third tasseled-cap band is often interpreted as an index of “wetness” (e.g., soil or surface moisture) (Lobser & Cohen, 2007).

We have rejected this indexes because for our purpose the NDVI was more used in literature.

The Normalized Difference Vegetation Index (NDVI) is an index of the photosynthetic activity of a plant (goes from -1 to 1) commonly used, it’s based on the assumption that live green plants absorb the light in the PAR (photosynthetically active radiation), that goes from 0.4 to 0.7 μm , and strongly reflects near-infrared light (from 0.7 to 1.1 μm).

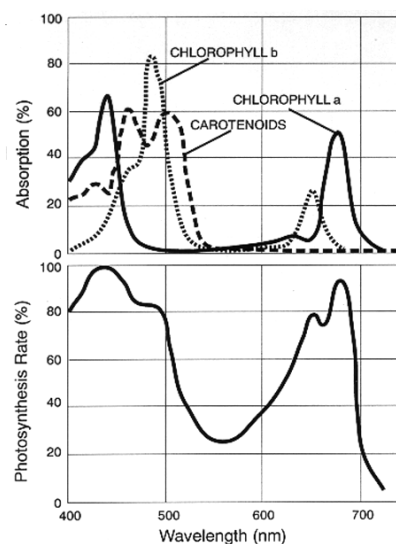


Fig. 1.2: PAR action spectrum and chlorophyll absorption spectra (GS Singhal et al., 1999).

Satellite remote sensors can quantify what fraction of the photosynthetically active radiation is absorbed by vegetation. Once taken the data of the reflectance of the surface the NDVI can be calculated by using the formula:

$$NDVI = \frac{(NIR-VIS)}{(NIR+VIS)} \text{ Fr. 1.1}$$

Where:

- NIR is the spectral reflectance acquired in near-infrared regions.
- VIS is the spectral reflectance acquired in the visible (red).

These spectral reflectances are themselves ratios of the reflected over the incoming radiation in each spectral band individually, hence they take on values between 0.0 and 1.0. We will have a result close to -1 in an area covered by snow or clouds for instance (but values less than zero typically do not have any ecological meaning) and a result close to 1 in a high vegetated area.

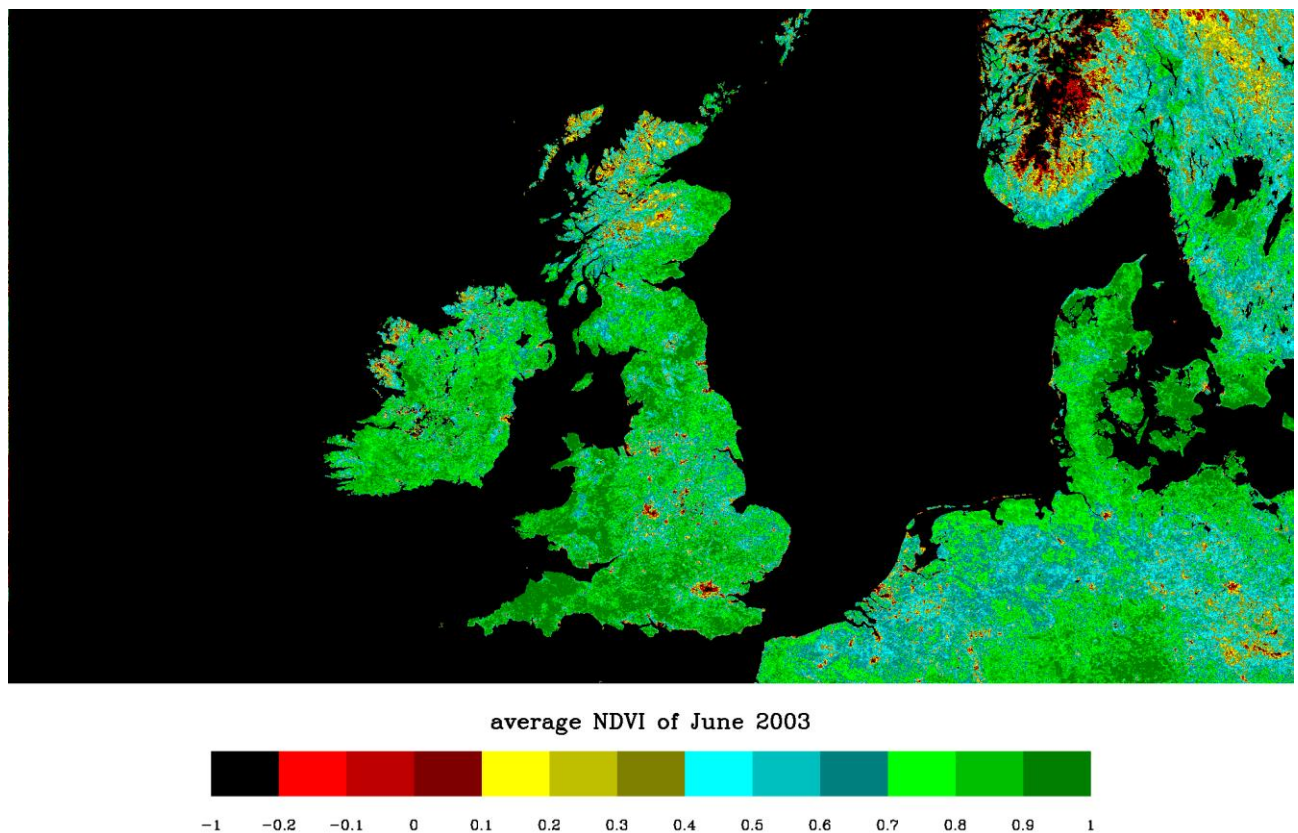


Fig. 1.3: example of average NDVI in June 2003 over the British isles (www.seiswave.com, 2014).

The story of NDVI is closely correlated to the start of the Landsat program. The launch of the Landsat 1 was in the 1972 and it was integrated with multispectral scanner that allowed to investigate also into the spring vegetation gree-up and the subsequent summer and fall dry-down. But to overcame the problem of the differences in solar zenith angle cross, Donald Deering, Robert Haas and John Schell developed the ratio of the difference of the red and infrared radiances over their sum as a means to adjust or normalize the effects of the solar zenith angle in the 1973.

The normalized difference vegetation index is one of the most useful and used index to quickly indentify vegetated areas with the use of multispectral remote sensing data.

The NDVI was used over time in many different aspects:

- Vegetation dynamics/Phenology over time (Wellens, 1997).
- Biomass production (Anderson et al., 1993).
- Grazing impacts/Grazing management (Hunt & Miyake, 2006).
- Change detection (Minor et al., 1999).
- Vegetation/Land cover classification (Geerken et al., 2005).
- Soil moisture estimation (Wang et al., 2004).
- Carbon sequestration/CO₂ flux (Hunt et al., 2004).
- Wildlife management (N Pettorelli et al., 2011).

In this thesis we will focalize on the use of NDVI in the wildlife management to discover the behavior of a group of ibex female in the Alps.

1.1.3 NDVI and wildlife management

The importance of NDVI comes from the fact that it gives information about a primary production (vegetation) over time (Pettorelli et al., 2011).

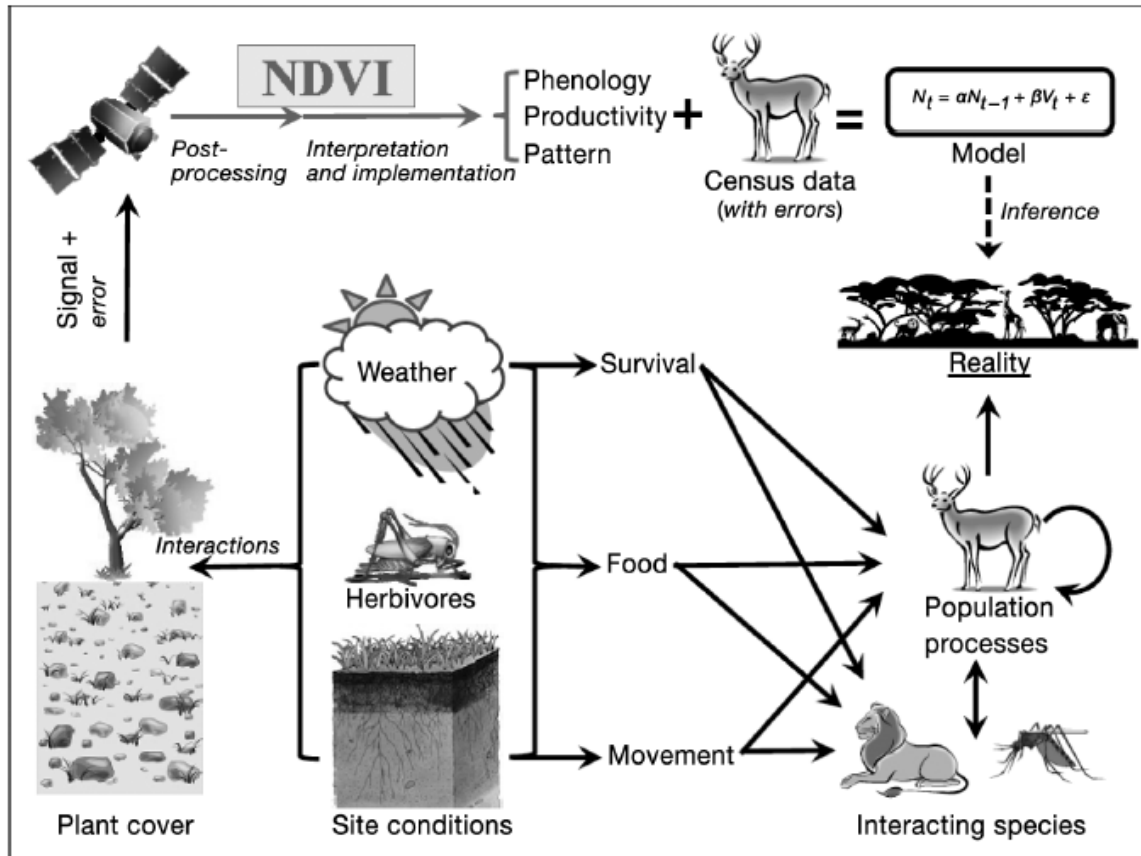


Fig. 1.4: schematic representation of interaction between vegetation and animals, and how NDVI can be useful (Pettorelli et al., 2011).

This gives the opportunity to study the species related to this primary production and their behavior with its changes, and can also help the wildlife distribution models (Suárez-Seoane, Osborne, & Rosema, 2004). It's possible to find a rich information in literature about the correlations of NDVI (as a proxy of vegetation growth) with movements of large herbivores, that are strongly related to the access to better forage (Fryxell & Sinclair, 1988). One example is the study about the interaction between climatic variability (measured by the North Atlantic oscillation 'NAO'), vegetation phenology (estimated with NDVI) and red deer (*Cervus elaphus*) body mass and movement in Norway (Nathalie Pettoirelli, Weladji, et al., 2005b), which found that earlier springs can cause a faster growth of vegetation that leads to an increase in the body mass and to earlier migrations to summer ranges.

Other examples that underline the benefits of NDVI in wildlife studies can be:

- The estimation of vegetation growth by NDVI and of its influence on migration patterns of Blue Wildebeests *Connochaetes taurinus* in the Serengeti (Boone et al., 2006).
- The correlation between wet-season home-ranges of elephants and the seasonal vegetation productivity in southern Africa (Young et al., 2009) or between elephants diet and NDVI variation in Kenya (Wittemyer et al., 2009).
- The use of NDVI as a good predictor to assess the body mass of roe deer and reindeer in France and Norway (Nathalie Pettorelli et al., 2006; Nathalie Pettorelli et al., 2005c).

Another study that is important to discuss is one on African buffalo that first was assessed the correlation between the quality of food (using NDVI) and occurrence/synchrony of births, and discovered a correlation between NDVI and plant nitrogen content with data from field surveys (Ryan et al., 2007)(Fig. 1.5). This underlines how NDVI can be a good proxy for estimating vegetation quality for herbivores.

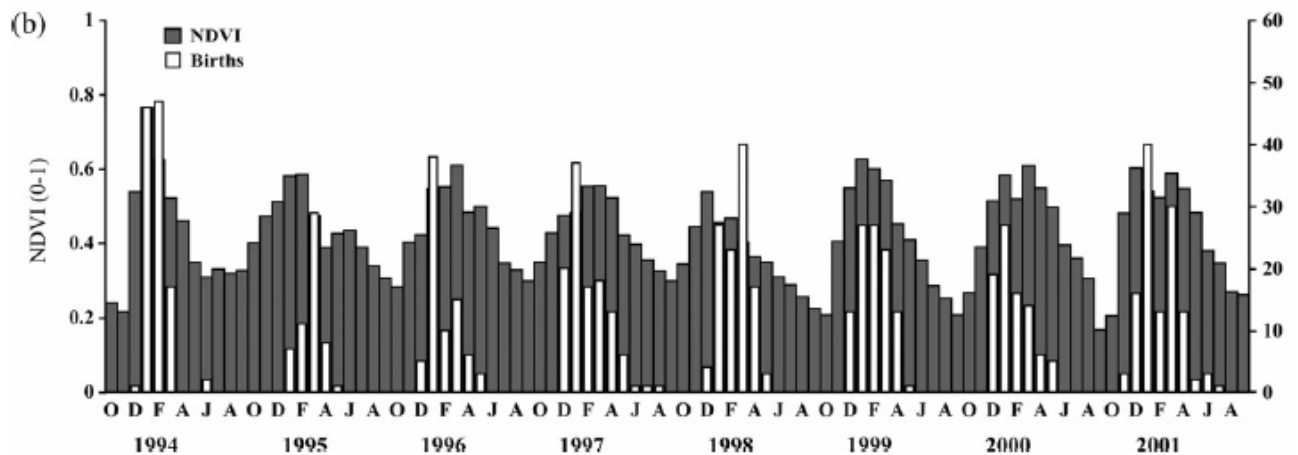


Fig. 1.5: NDVI in grey and monthly births in white (Ryan et al., 2007).

1.2 Alpine ibex

This thesis will focus on the Alpine ibex (*Capra ibex ibex*), the subspecies of *Capra ibex* that can be found in the European Alps. Other subspecies are: *Capra ibex sibirica* or Siberian ibex, which is distributed in north Asia, Kashmir, Pakistan and north-western Afghanistan, *Capra ibex nubiana* or Nubian ibex, present in middle east and northern Egypt, *Capra ibex walie* or walie ibex distributed in the Semien massif and *Capra ibex caucasica* distributed in western Caucasian (Scillitani, 2011).

The Alpine ibex in the past centuries was present in all the Alpine arcs, but due to overhunting, especially following the introduction of firearms, it was almost extinct at the end of 19th century, and at the beginning of the 20th century only few individuals survived in the Gran Paradiso massif (50 or 100 ibex). The recovery of the species started when a Savoy royal law created in the area a royal hunting estate and prohibited any other hunting; the king enrolled also gamekeepers from local communities to stop poaching.

The rescue of the species was further helped in the 1922, when the Gran Paradiso became the first national park in Italy. During the following decades the species was able to increase locally and to recolonize the alps, thanks to many reintroductions projects. Now, the Alpine ibex is present in all the Alpine countries, with an estimated population size of 47.000 animals divided in 150-160 colonies according to the survey conducted by the Institute for Environmental Protection and Research (ISPRA, 2013). Today alpine ibex is no longer at risk of extinction, it is classed as “Least Concern” by IUCN (Temple & Terry, 2007). An important factor to take into consideration is, however, that these populations have a low genetic variability due to the low number of individuals used for reintroductions and to the same origin of the colonies (one of the lowest ever seen in mammals).

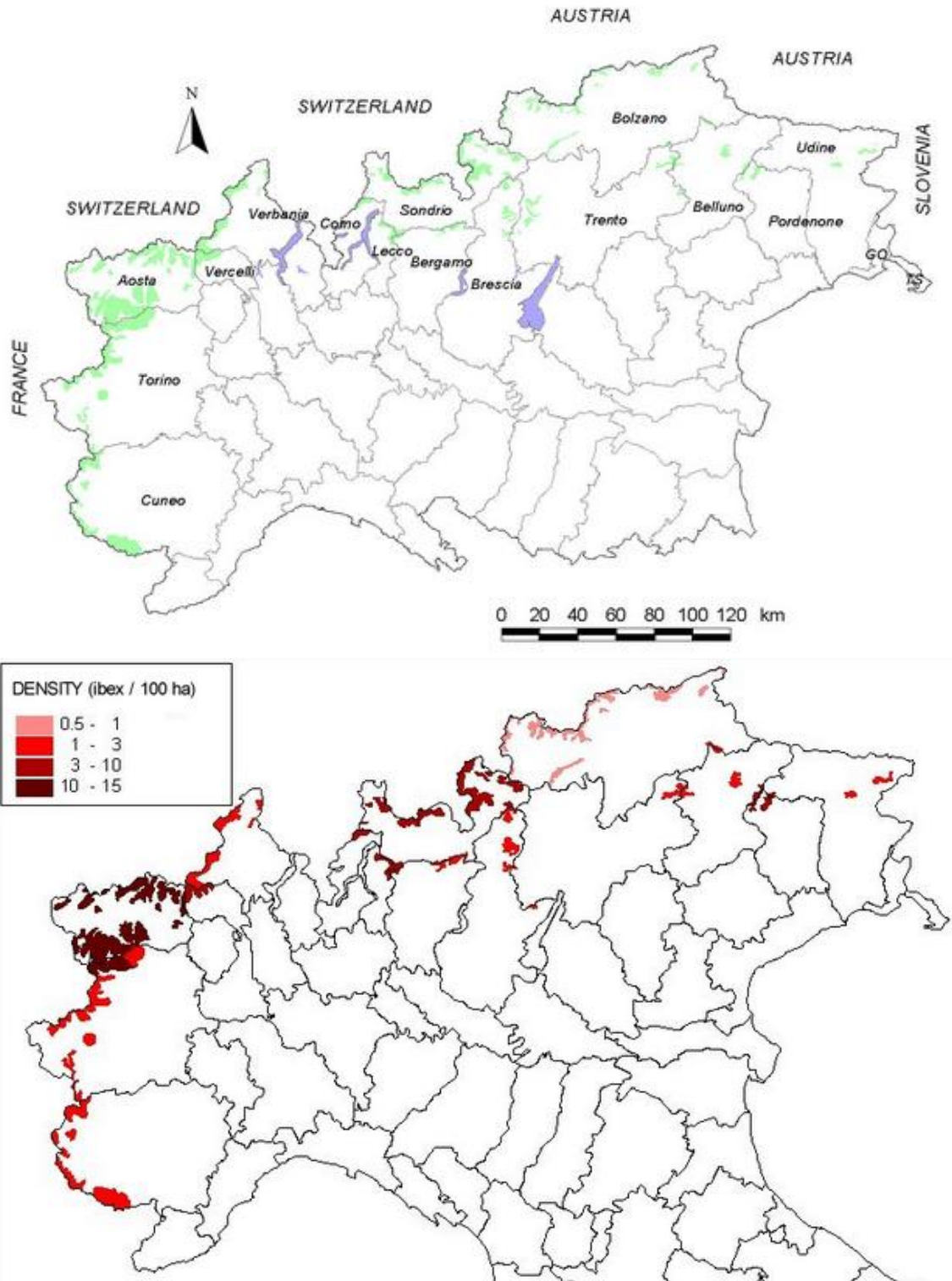


Fig. 1.6: Distribution (green) and density (red) of ibex in the Alps 1999-2000 (<http://biocnosi.dipbsf.uninsubria.it/LHI>, 2014).

In addition at least 30% of the colonies in the Alps count less than 100 individuals, which can lead to problems of inbreeding and lower resilience after stochastic events (Berger, 1990). Moreover, in the eastern Alps the ibex populations are threatened by sarcoptic mange epidemics, which may cause catastrophic declines (Rossi et al., 2007). The Gran Paradiso population is declining, and from 1993 to 2009 it has halved its size, probably because of different density dependent causes and climate changes (Jacobson et al., 2004).

This species has many peculiarities among the European wild bovids. It is a sexually dimorphic species: the maximum body size is reached at six years for females (60 kg) and nine-eleven years for males (100 kg, 120 kg in late autumn) (Giacometti et al., 1997); females have much shorter horns than males (maximum 34 cm female, 98 cm male). The Alpine ibex can live up to 19 years, although senescence starts earlier in males (Carole Toïgo et al., 2007). Sexual maturity can be reached at 1,5 years in both sexes, but young males are prevented from reproducing by older, dominant males. In addition, the population density factor can delay first reproduction in females (Parrini, Cain, & Krausman, 2009). The mating season starts in December and lasts around six weeks; the gestation lasts around 167 days, with twins in 0-20% of the births. Outside the mating season sexes are spatially segregated, in gregarious communities of males or females with kids, yearlings and occasional subadult males (C Toïgo et al., 1996). The habitats used by Alpine ibex are also peculiar, comprising steep rocky areas, even with poor vegetation as scree and high-elevation grasslands interspersed with bare soil and rocks, in a range from 1600-1800 to 3500 m.a.s.l, with the highest elevations in summer and the lowest in winter-spring. (Wiersema, 1989). This is very interesting for this thesis, because the studies on the relationships between wildlife and NDVI have so far focused on species using highly vegetated areas, as above summarized.



Fig. 1.7: female of alpine ibex (<http://en.wikipedia.org/>, 2014)

1.3 study area

Our study area is located in the Marmolada massif, in the northeastern Italian Alps; It has the highest peak (“Punta Penia”, 3343 m.a.s.l.) of the Dolomites. It is part of a group of mountains that takes its name, and can be divided into various subgroups or chains (Marazzi, 2005): Marmolada massif, Padon chain, Colac-Buffaure subgroup, Ombretta-Ombrettola subgroup, Cime d’Auta chain, Vallaccia-Monzoni subgroup and Cima dell’uomo chain.

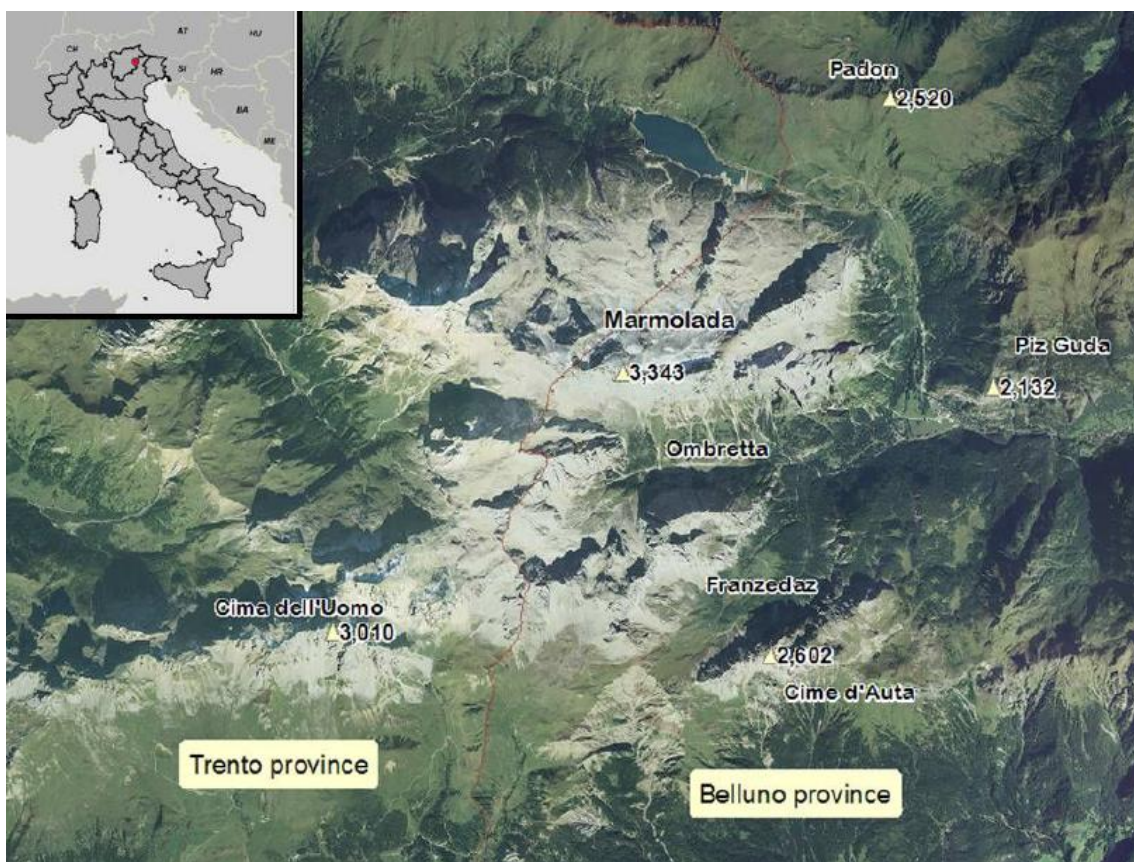


Fig. 1.8: overview of the study area, the massif of the Marmolada (Scillitani, 2011).

The whole area extends for 150 km² and it has as geographical limits at north “passo Pordoi”, at south the valley of San Pellegrino, at east the Cordevole river and at west the valley of Fassa.

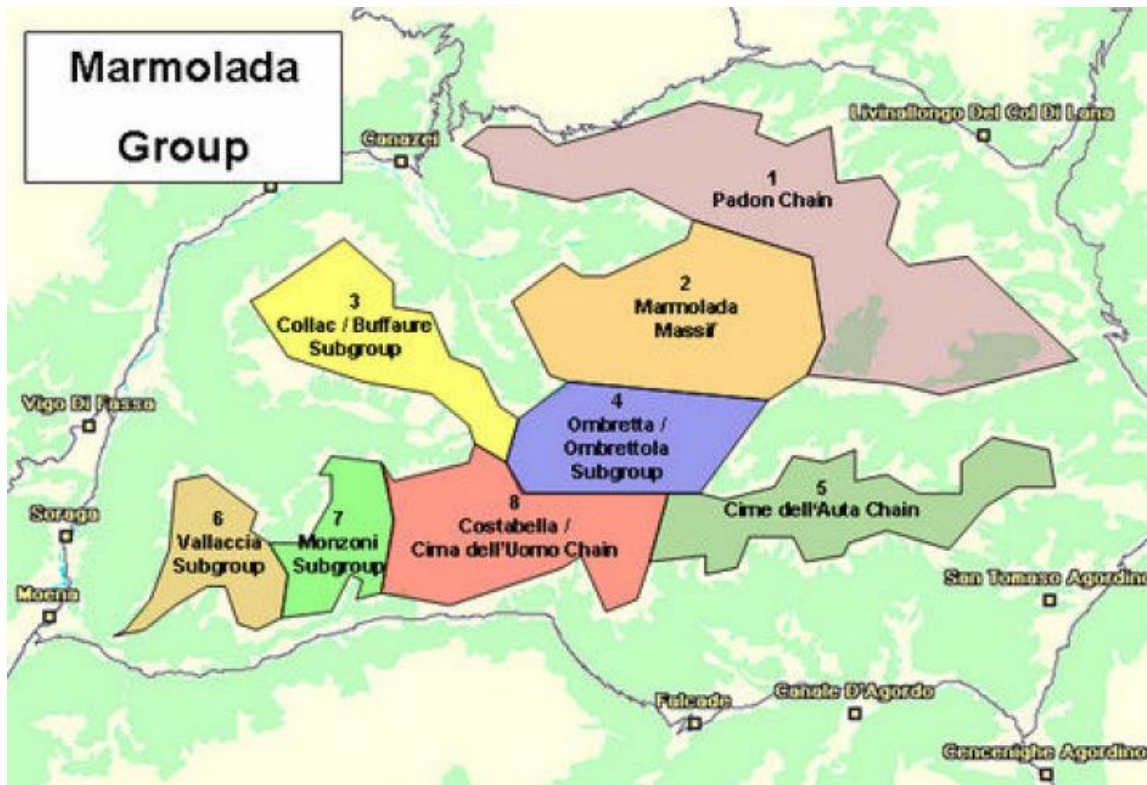


Fig. 1.9: overview of Marmolada group and subgroup in different color (Scillitani, 2011).

The study area is shared between the administrative province of Trento (Trentino Alto Adige region) and the province of Belluno (Veneto region), and despite its name the Marmolada massif is composed mainly by hard limestone with inserts of volcanic material. A glacier is present at the top of the Marmolada mountain, but it covers the 2% of the total area. The vegetation follows the typical mountain gradient, at the lowest altitudes we find mixed woodlands composed by *Fagus sylvatica*, *Fraxinus excelsior* and *Acer pseudoplatanus* and *Picea abies*. Above 1600 m, the tree composition changes, with again *Picea abies* but with an increasing presence of *Larix decidua* until the timberline, after which stands area composed by *Larix decidua*, *Pinus mugus* and *Alnus viridis* forming the treeline; In this area typical herbaceous species are *Carex sempervirens* and *Sesleria varia*. The alpine ibex is not the only mammals living in this mountain, we have other herbivores species: *Rupicapra rupicapra*, *Capreolus capreolus*, *Cervus elaphus*, *Ovis gmeini musimon*. However, only *Rupicapra rupicapra*, which is present at small densities, overlaps partially its range with that of ibex. There are no ibex predators for ibex in the Marmolada, expect for occasional sporadic attacks by golden eagle to kids.

1.4 Objectives

This thesis aims to verify the relation between NDVI, as a proxy for vegetation quality, and the movement and habitat selection of Alpine ibex females in the Marmolada area. I will try to relate the land use with the NDVI and the GPS position of the ibex recorded, in order to discover possible relationship between the Alpine ibex behavior and their use of the resource, despite of the complexity of high mountain area, where can easily occur noise from the presence of snow, rocks or bad atmospheric conditions.

2. Methodology

2.1 Data sources

My aim was to assess whether there is a correlation between the presence of Alpine ibex in a specific area or pixel and the vegetation quality of the pasture in that specific point. For this reason we need two different types of data, the daily locations of the animals and estimates of vegetation greenness.

About the vegetation I have used the NDVI as a proxy, because it is a good indicator of the photosynthetic activity of plants and I have found other different studies that have used this index for similar purpose (see chapter 1.1.2 Vegetation Indices).

In order to have the possibility to calculate the values of NDVI of the area I have used satellite images in TIF format (tagged image file format), which is able to associate different bands to the same image. I have used the Landsat 8 (L8) images because of their better quality and because the Landsat 7, since the 2003, has imperfect images due to a damage to its sensor.

The bands of the L8 are:

- Band 1: coastal aerosol (wavelength 0.43 – 0.45 μm).
- Band 2: Blue (wavelength 0.45 – 0.51 μm).
- Band 3: Green (wavelength 0.53 – 0.59 μm).
- Band 4: Red (wavelength 0.64 – 0.67 μm).
- Band 5: Near infrared (wavelength 0.85 – 0.88 μm).
- Band 6: SWIR 1 (wavelength 1.57 – 1.65 μm).
- Band 7: SWIR 2 (wavelength 2.11 – 2.29 μm).
- Band 8: panchromatic (wavelength 0.50 – 0.68 μm).
- Band 9: cirrus (wavelength 1.36 – 1.38 μm).
- Band 10: thermal infrared 1 (wavelength 10.60 – 11.19 μm).
- Band 11: thermal infrared 2 (wavelength 11.50 – 12.51 μm).

All the bands are with a resolution of 30 meters, for the calculation of NDVI I have taken the bands 4 and 5.

I have downloaded the maps from the United States Geological Survey (USGS), that is a scientific agency that works and studies on landscape, ecosystems and natural hazards. From the website "<http://earthexplorer.usgs.gov/>" it is possible to download the images for free.

For the acquisition of position data of the Alpine ibexes I used GPS locations collected from April 2013 to May 2014 from 17 females (estimated age ranged from 2 to 12 years) fitted with GPS Plus Collars (Fig. 2.1).



Fig. 2.1: radio collar used for the ungulate.

The radiocollars were scheduled to attempt to record an animal location every 1 hour. Data was received on a GSM Ground Station and downloaded and processed using a specific software (GPS Plus Collar Manager© 3.11.3, Vectronic Aerospace GmbH).

2.2 Data treatment and analysis

During each step of the data processing and analysis I have used principally three different softwares: SAGA GIS, QGIS, EXCEL.

EXCEL is a spreadsheet application that we used to manage and store the variables obtained from the data processing. SAGA GIS 2.0.8 (system for automated geoscientific analyses) is a GIS (geographic information system) used for editing spatial data; it's a practical tool because it is not a heavy program and moreover it's not necessary to open the images in order to work with the data. This is very useful because is possible to do a fast work also with big images. QGIS (version 2.3.0) is another free and open source GIS, like SAGA, but is more useful when one wants to look to the images.

During the replication process for the validation of the results it is important to do again precisely what has been done, and for this reason I will describe step by step all the steps done during the processing of these data.

The first step is to cut from the satellite map the area of interest, in order to have for the next steps lighter files to manage.

I Opened SAGA GIS and loaded the shapefile of the area and the satellite map. Using the algorithm *clip grid with polygon* (*modules* → *shapes* → *grid* → *spatial extent* → *clip grid with polygon*) I created the cut map, I selected in the map in grid system and in the output I have imported all the bands in the correct order (from 1 to 11), in polygons I selected the study area (Fig. 2.2).

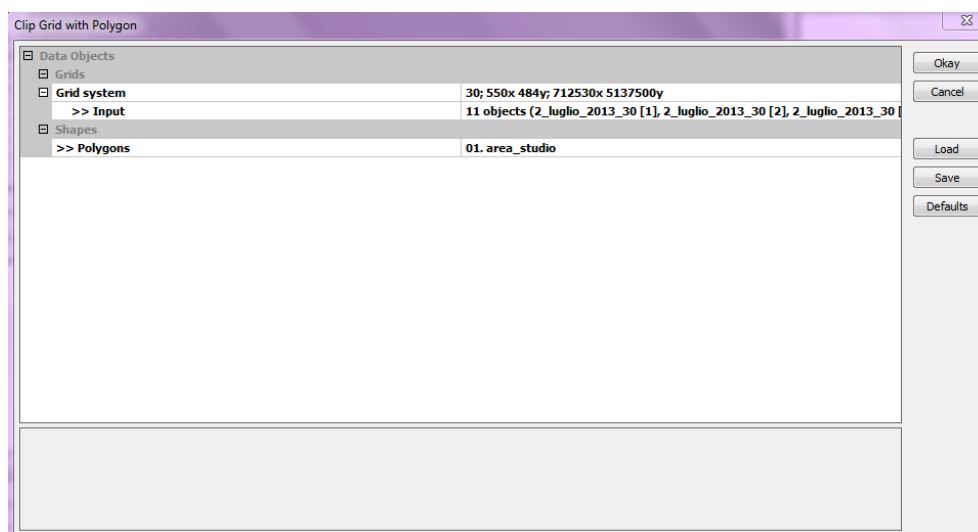


Fig. 2.2: extraction of the study area from the satellite map.

Once created the new map, the next step to do in SAGA is to create the NDVI map, where each pixel is given its value of NDVI. In order to do this, I have to use another algorithm: *grid calculator* (*modules* → *grid* → *calculus* → *grid calculator*). In grid system I selected the right map and in grid the right bands, in this case for the calculation of NDVI, I selected first the band 4 and then the band 5. I have keyed the formula of NDVI, taking into consideration that the program considers the letter “a” as it is the first selection and “b” for the second (Fig. 2.3).

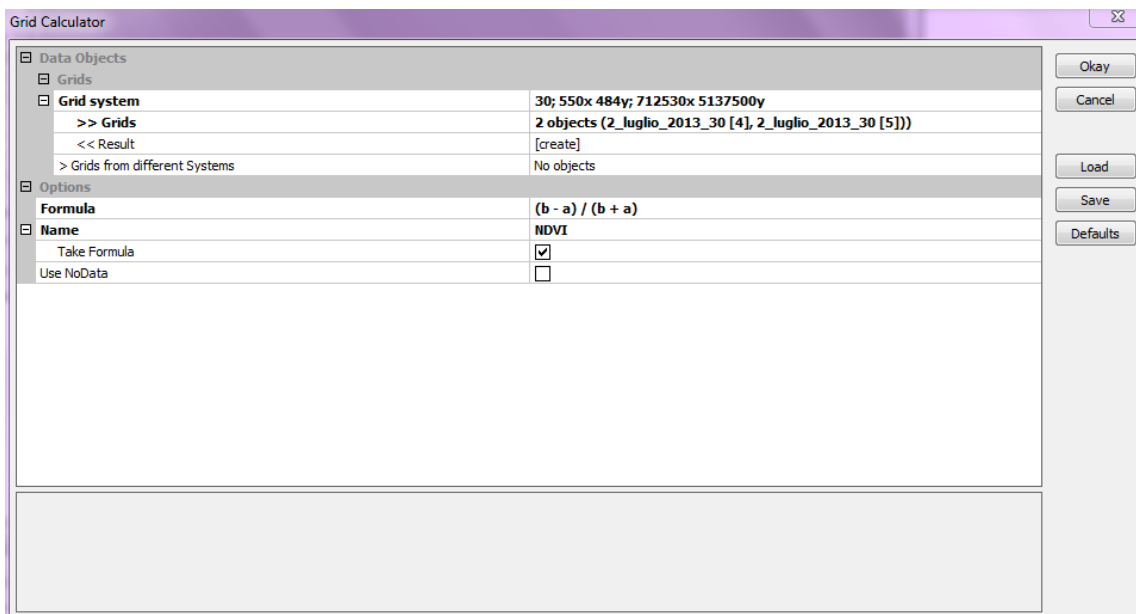


Fig. 2.3: creation of the NDVI map.

The last step in SAGA GIS is to export the maps that we have created using the algorithm *GDAL: export file to geoTIFF* (*modules* → *file* → *GDAL/OGR* → *GDAL: export file to geoTIFF*). As before I selected in grid system the map, and in grid the bands in the right order (for NDVI map there is just one band) and finally I have chosen the directory where to save the file.

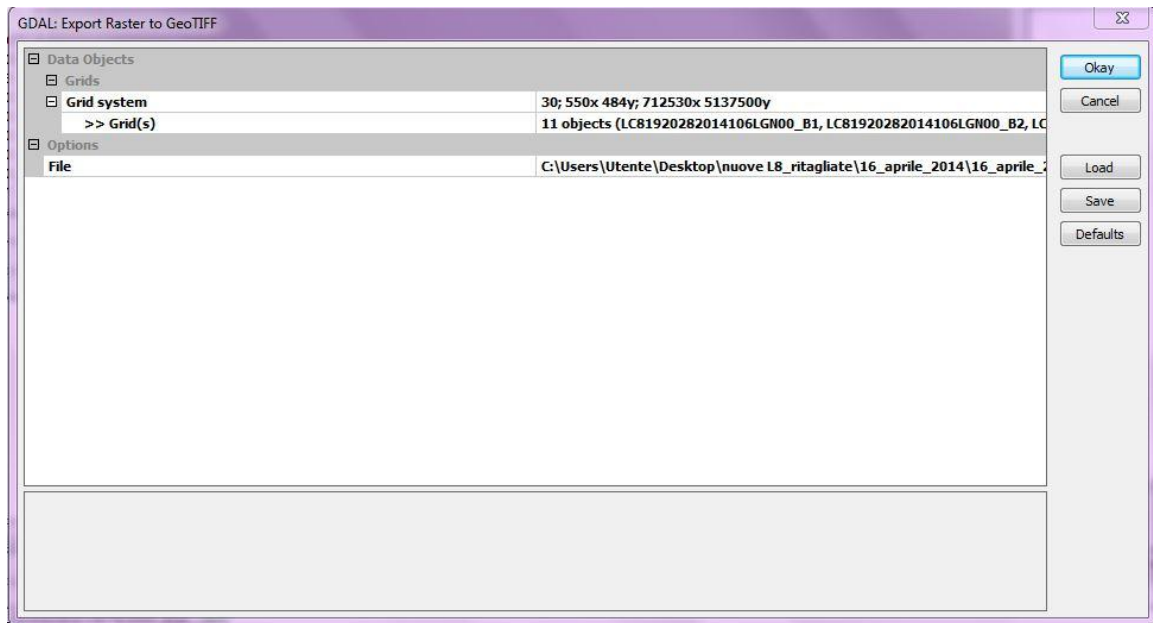


Fig. 2.4: illustration of the algorithm that save the file in a georeferenced system.

In order to join the animals positions with the NDVI values, I have to create a shapefile with the coordinates of the animals from the database with the positions.

Starting from the excel file with the data of positions for the same date of the map, I needed to save it as csv (comma-separated values) in order to open it in a GIS. With the help of QGIS I was able to transform this file into a new shapefile in a georeferenced system.

I had to go to *layer* → *add delimited text layer*, browse my csv file, put custom delimiters and select the semicolon, then I just had to put for the X field the longitude colon and for the Y field the latitude colon, the program will take them as coordinates (Fig. 2.5).

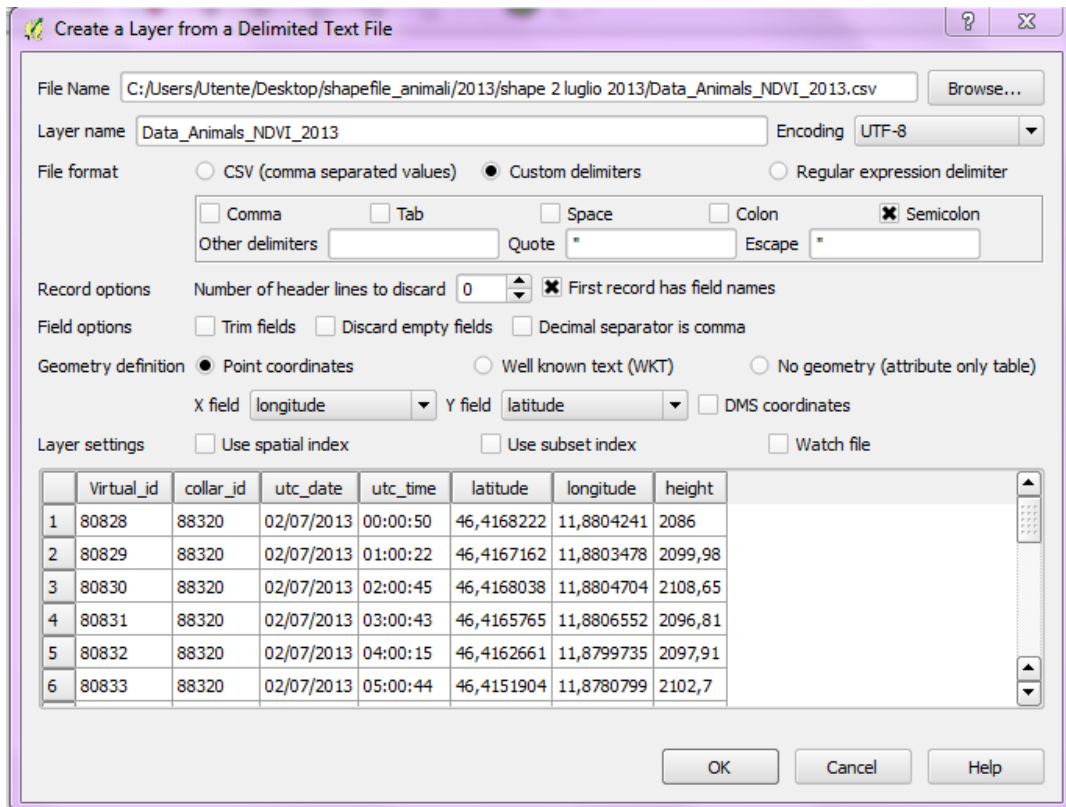


Fig. 2.5: creation of the shapefile with the animals positions.

After the creation I had to save it, select the new shapefile in the layer box in your left, click with the right mouse button and select *save as*. I have put as format the ESRI shapefile, chosen the directory to save the file and put as layer CRS the WGS 84 /UTM zone 32N (the WGS 84 is the system utilized by the global navigation satellite systems GPS) (Fig. 2.6).

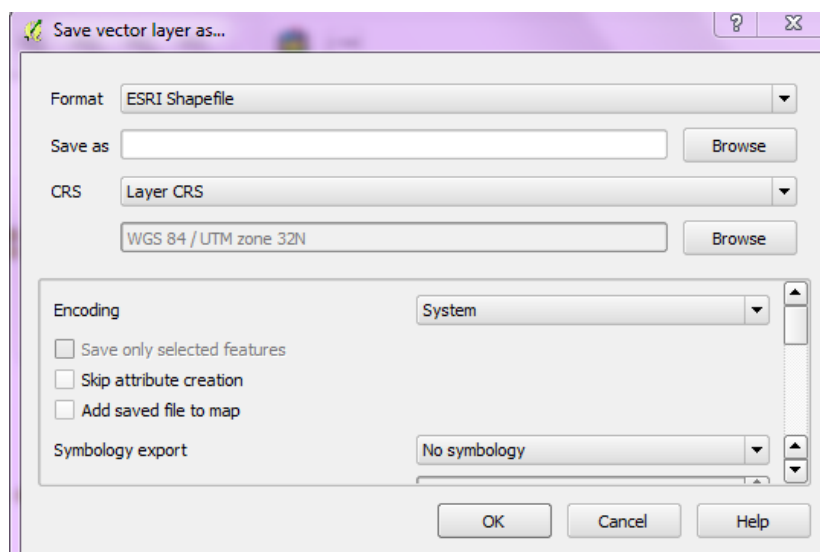


Fig. 2.6: saving of the shapefile.

I opened a new project with the shapefile of the animals positions and the cut satellite map, I used the plugin: *pointing sampling tool* to join the positions of the animals with the value of the bands 4 and 5 of the same pixel, in this way I can calculate the value of the NDVI of the pixel where there is the Alpine ibex (Fig. 2.7).

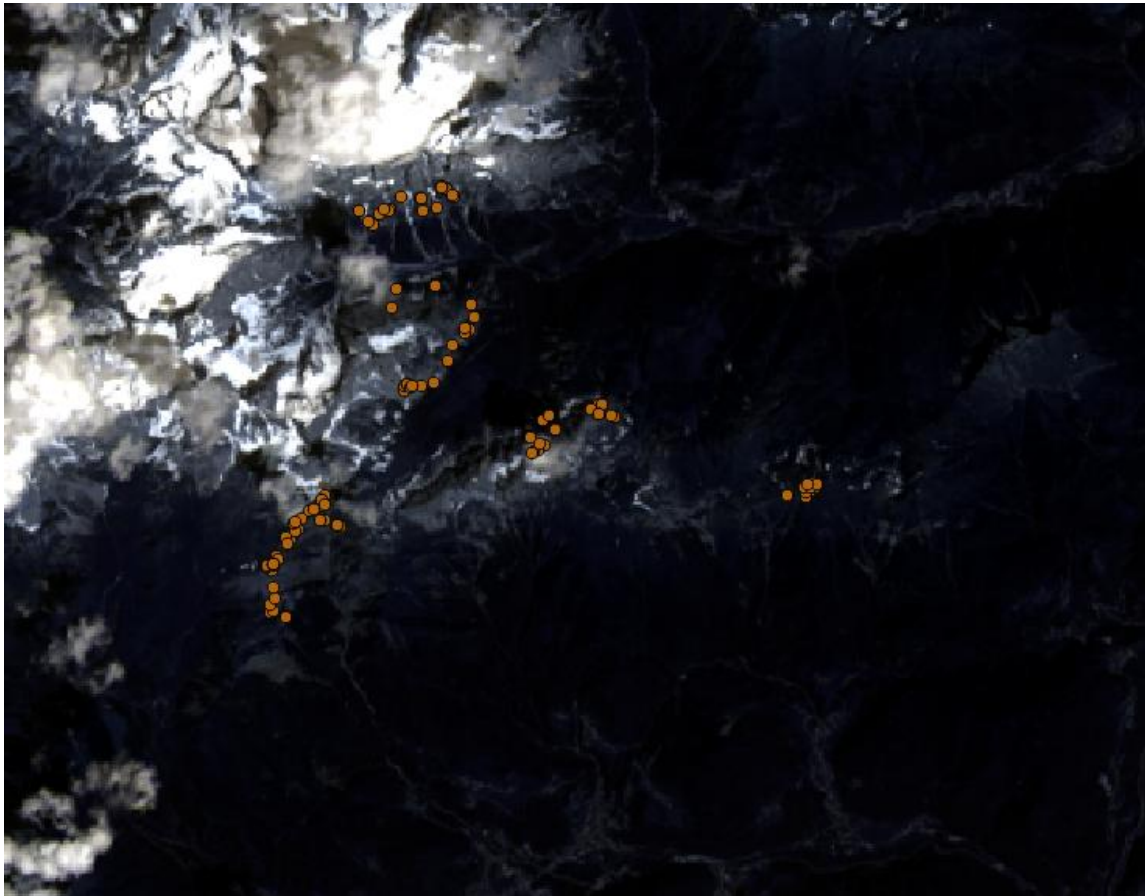


Fig. 2.7: example of the animal points in the satellite map.

I opened the point sampling tool, I select the right layer and all the data that I needed to put in the new shapefile (the id of the collar, the date and time of the acquisition of the animal position, the latitude and longitude, the elevations and the bands 4 and 5) (Fig. 2.8).

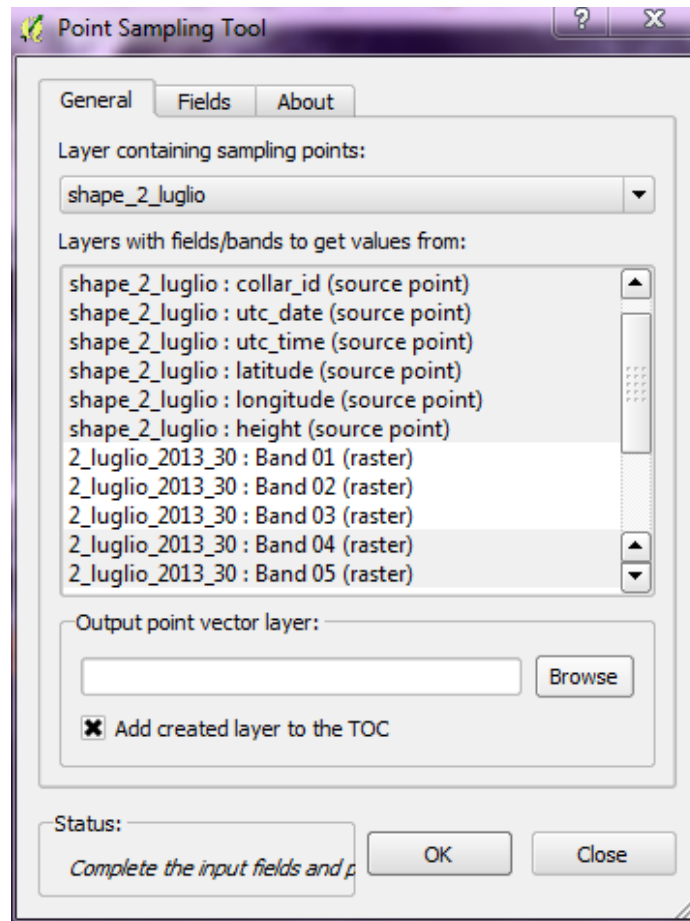


Fig. 2.8: the pointing sampling tool utilization.

After that, I opened the dbf format of the shapefile with excel and copy the data in a new database, I had to do it because I hadn't to modify this file or I will damage the shapefile. In the new database I applied the NDVI formula in order to have the values for all the animals positions.

In order to compare the NDVI values of the animals I have tried two type of approaches, one calculating some information of an area buffering around the gps position of the Alpine ibex and the other one taking into account other random points.

For the zonal statistic I opened in QGIS the NDVI map and the animal shapefile of the same date, then I had to create a new colon in the attribute table of the animal shapefile concatenating the colon of the collar id and of the date. After this I needed to apply the command to create convex polygons (vector → geoprocessing tools → convex hull), i chose the as layer the shapefile and select *create convex hulls based on input field*, then I chose the new colon that I have created before (Fig. 2.9).

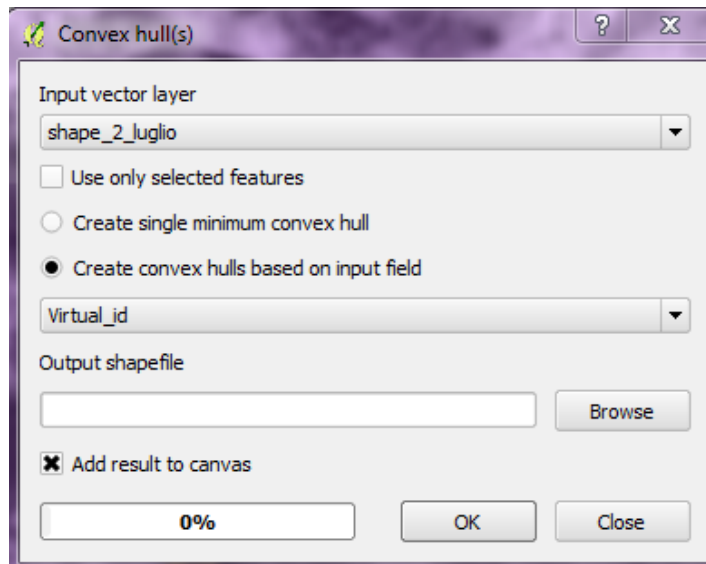


Fig. 2.9: creation of the convex polygon.

Now I have saved the new level in a projected referenced system (such UTM), the next step was to add a buffer to our polygons, using the *command buffer (vector → geoprocessing tools → buffer)*, I selected the polygons layer put 5 segments to approximate and a buffer distance of 120.

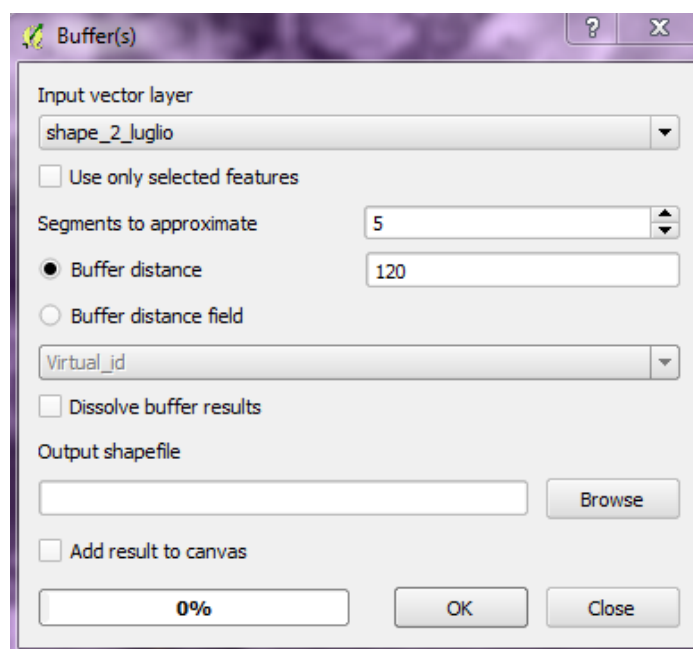


Fig 2.10: buffering of the polygons.

Now with the use of the algorithm *zonal statistic* present in QGIS I was able to extrapolate some statistic information from our polygons (minimum and maximum value of the NDVI of

the polygons, the mean NDVI, the standard deviation and the covariance). I selected the NDVI map as raster layer and the buffered polygons as vector layer, then I saved the new file in your directory (Fig. 2.11), after that I had to copy the values I needed from the dbf format of the shapefile in another database, like in the step of calculation of the values of animals' NDVI.

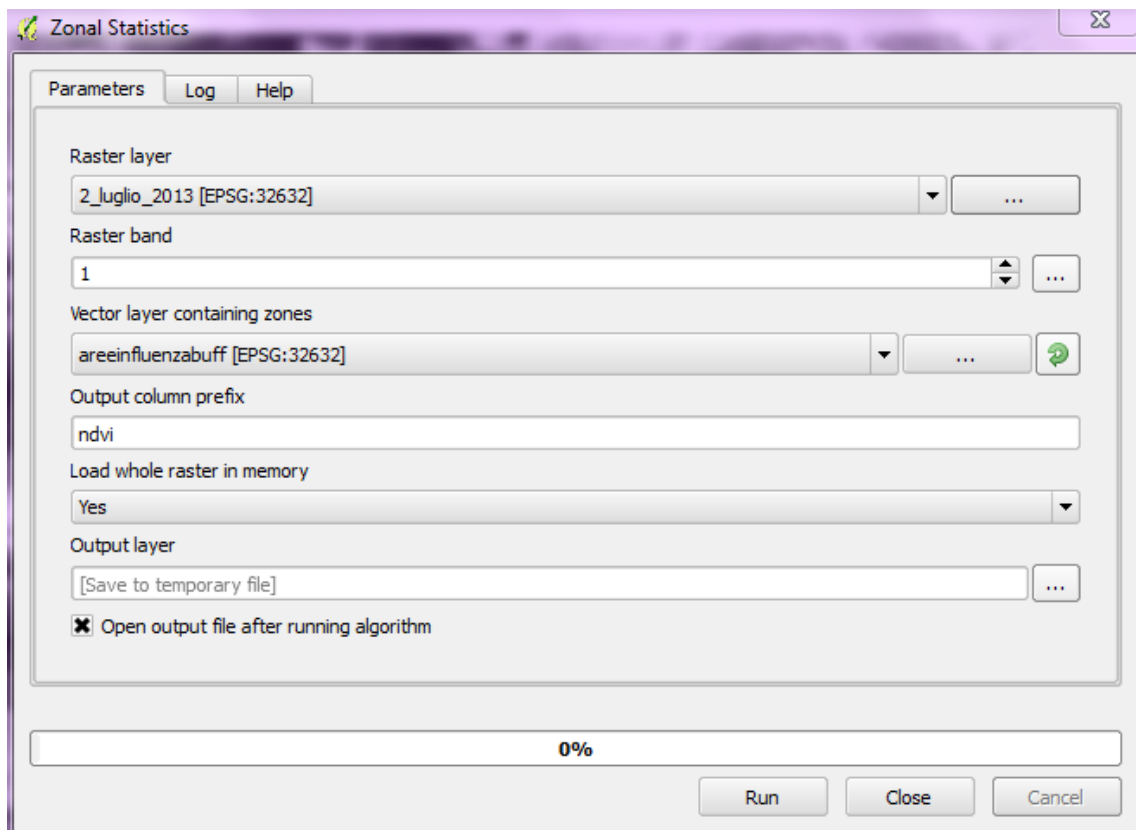


Fig. 2.11: zonal statistic algorithm.

Another important step was to create random points that can be matched with the real positions of the Alpine ibex, I will use the results to see if the values of NDVI of random points are more or less then the real one.

To create random point I used EXCEL, taking in to account that:

- 1° latitude correspond to 111159.0973 meters in the reference system WGS 84.
- 1° longitude is equal to 76903.17828 meters in the reference system WGS 84.

I created random point in a range of 30 meters around the position of the animal using the formula below:

$$Lat\ random = Lat + \cos(random\ angle) * (random\ distance) * A \quad Fr.\ 2.1$$

$$Long\ random = Long + \sin(random\ angle) * (random\ distance) * B \quad Fr.\ 2.2$$

Where:

- A is equal to 0,000269883 and is the equivalent of 30 meters in latitude grades.
- B is equal to 0,000390101 and is the equivalent of 30 meters in longitude grades.
- Lat and Long are the real latitude and longitude.
- Random angle is chosen by an algorithm of EXCEL from 0 to 360°.
- Random distance correspond to the distance from the real pixel, chosen by a algorithm of EXCEL from 1 to 4 pixels.

Then I created a shapefile using as coordinate the random points and we calculate the NDVI values with the use of QGIS plugin “*point sampling tool*”, such as I have done in the step where we calculated the real NDVI values.

For the correction of the bands taken from the satellite maps i have applied the conversion to TOA reflectance, provide from the USGS (http://landsat.usgs.gov/Landsat8_Using_Product.php).

The equation below (Fr 2.3) is used to convert DN values to TOA reflectance for OLI data:

$$\rho\lambda' = M_{\rho}Q_{cal} + A_{\rho} \text{ Fr. 2.3}$$

where:

- $\rho\lambda'$ are the TOA planetary reflectance, without correction for solar angle.
- M_{ρ} is band-specific multiplicative rescaling factor taken from metadata (reflectance_mult_band_x).
- A_{ρ} is the band-specific additive rescaling factor from the metadata (reflectance_add_band_x).
- Q_{cal} is the quantized and calibrated standard product pixel values (dn)

For the land use analysis I used the *pointing sampling tool* for associating to each animal position recorded information about the land use of the pixel and of the polygon of the animal, I divided the area in 7 classes:

- DF or dense forest.
- OF or open forest.
- OA or open area, correspond to grassland.
- R or rocks.
- SH or shrubs.
- SC or scree with scattered vegetation.
- U or urban area (we cut this classes because they were not useful for our purpose).

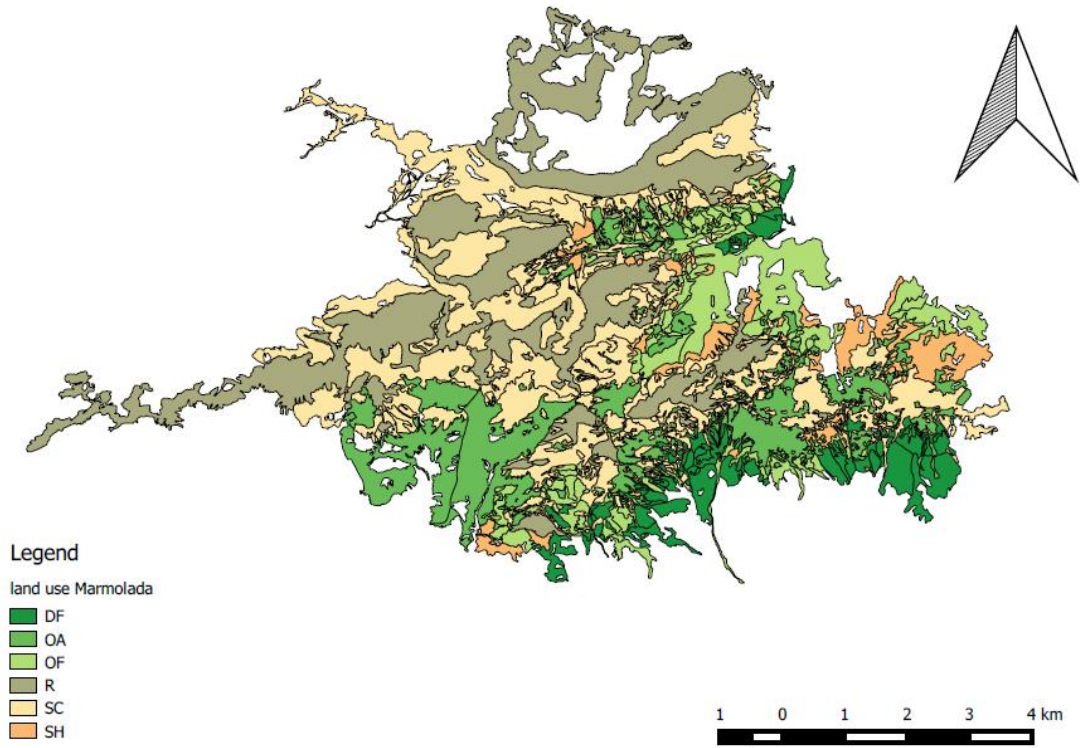


Fig. 2.12: land use map of the Marmolada.

3. Results and Discussion

3.1 Technical problems and vegetation indexes

One problem found is about the presence of clouds and generally the atmospheric conditions, that are a stochastic factors, I have eliminated from the dataset, due to this problem, many satellite maps and I considered only maps with a good visibility at least where there were the animal positions.

The other problem is the presence of snow during the winter and the rocks during the summer, which affects the NDVI values. These factors are naturally present in mountain areas and I have tried to avoid them taking into consideration the land use.

This problems have also influenced my decision of choosing the NDVI respect to the other vegetation indexes considered (brightness, wetness and greenness). In fact the indexes of brightness, wetness and greenness are related just to a transformation of the previous bands in news bands, created just pondering the old bands, instead the NDVI uses a ratio between two bands and the results are less influenced by the presence of bad atmospheric conditions. Moreover I have found that in literature the NDVI is more used, especially considering the animal ecology (N Pettorelli et al., 2011).

Anyway I used the greenness index to support some of my decision in the elaboration of data, for example the figure 3.1 shows that there is a linear relationship between the greenness index and the NDVI when considering vegetated land use as the open forest, moreover it is shown that the greenness index starts to be positive with a NDVI greater than 0,2. A useful information used when we decided the NDVI classes in the land use analysis.

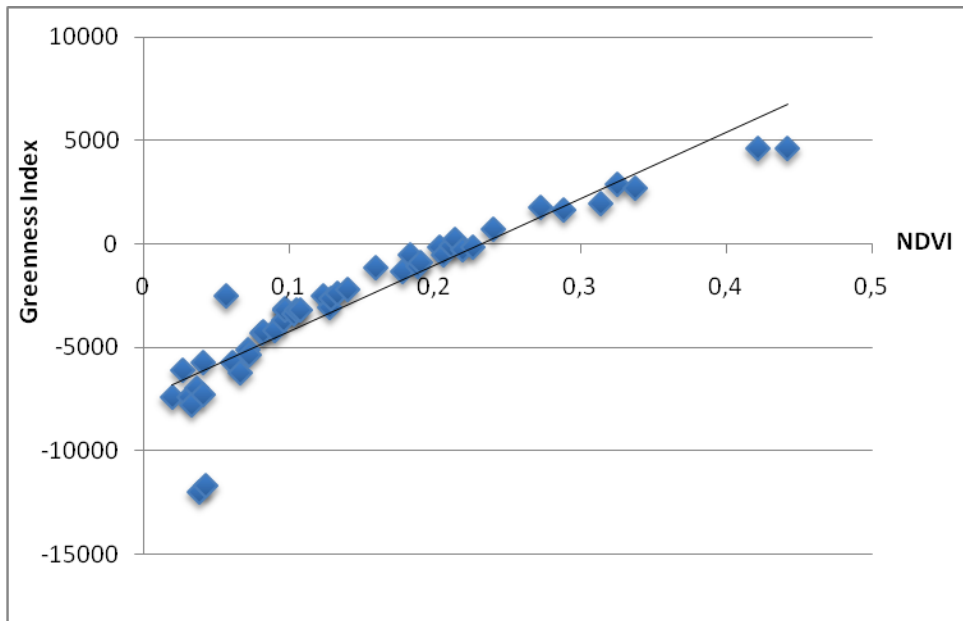


Fig. 3.1: linear relationship between greenness index and NDVI.

Another point is the correction of the bands using conversion to TOA reflectance, I have seen, as shown in figure 3.2, that there is a linear relationship between the normal NDVI and the NDVI corrected, considering this I decided to use for the land use analysis the normal NDVI because what I am looking for are not absolute values but I am interested in a comparison, that is not influenced by absolute values, when using percentage. Furthermore this allowed to use less step in the elaboration of data.

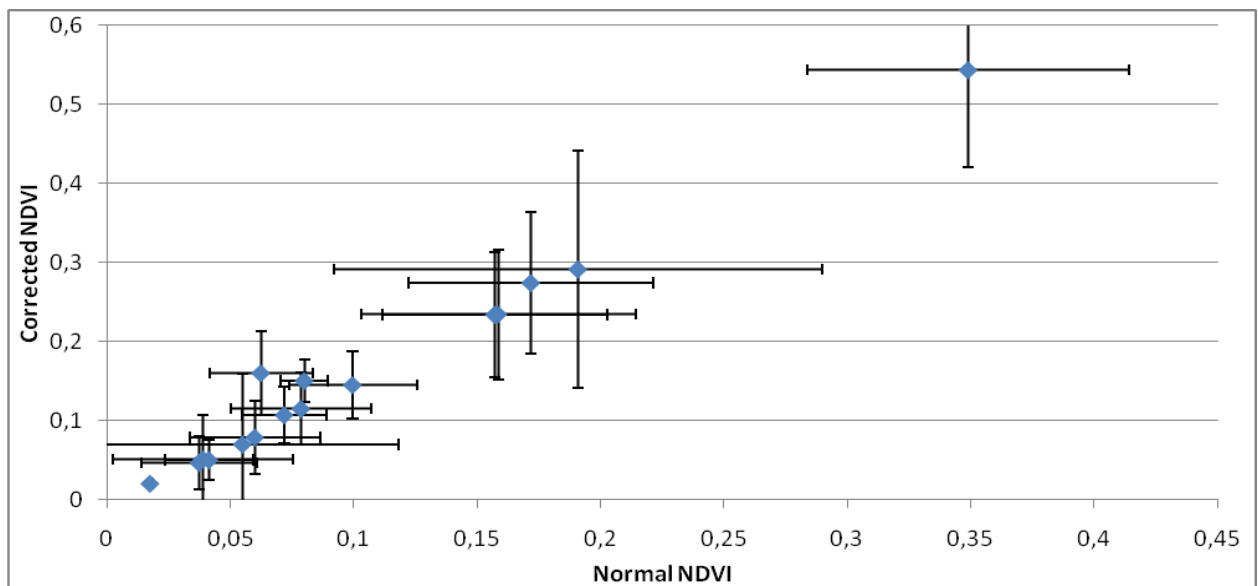


Fig. 3.2: linear relationship between the normal and corrected NDVI, the bars are the standard deviations.

3.2 NDVI and animal positions

The first evaluation of the distribution of the NDVI values over time is shown in figure 3.2, I can see that the highest values of NDVI are located in the summer time, which is obviously not surprising. However, it is also clear that in certain summer dates the NDVI values are very low. In blue there are the data coming from the real NDVI values of the animal position, in red the random position used to make the comparison and in green there is the average NDVI of the polygons per day. For this reason I decided to remove the data that come from maps where there were high percentage of clouds covering the positions of the animals, because the presence of clouds highly affects the bands (Gutman, 1991).

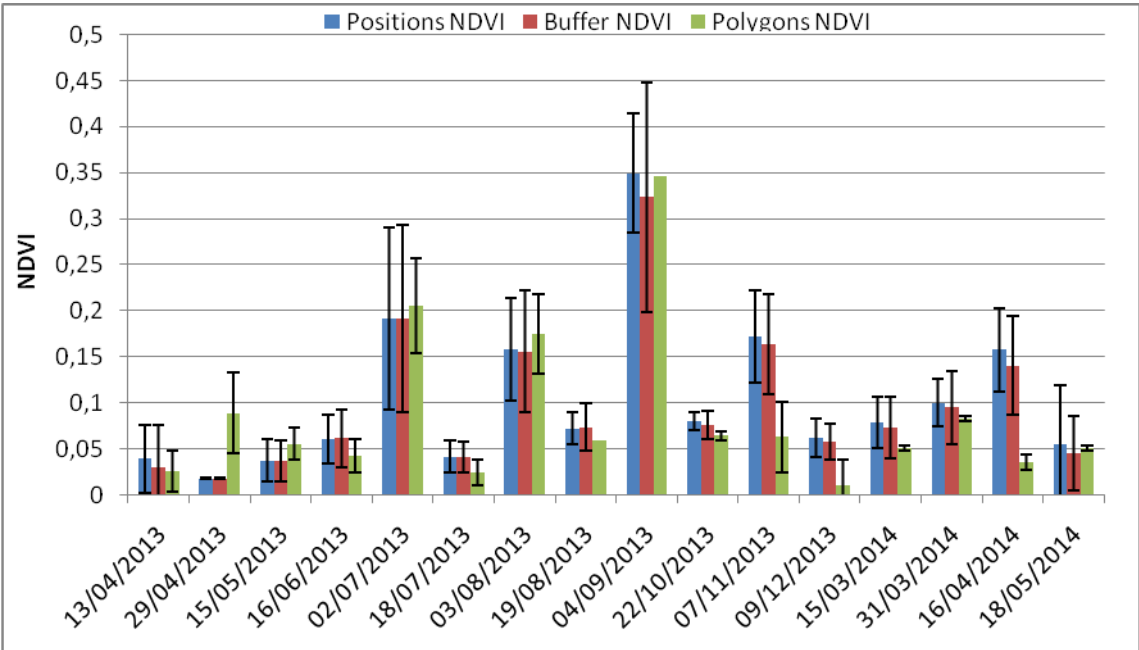
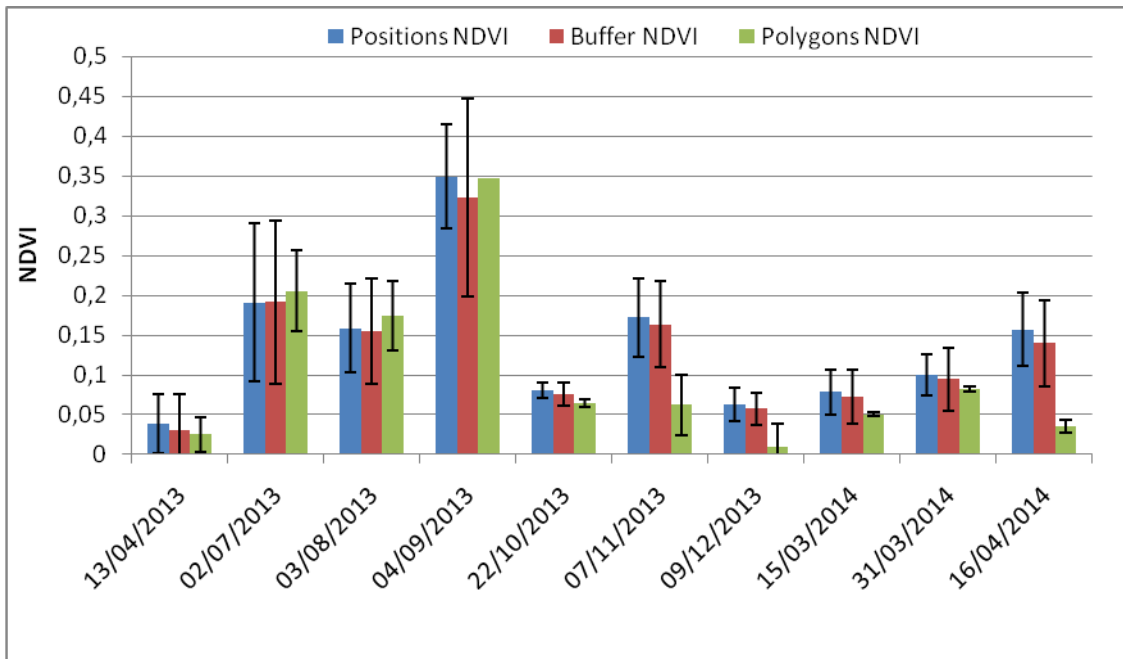


Fig. 3.3: average NDVI values for each day, for animals locations (positions NDVI), buffer random points (Buffer NDVI), and the average of the daily polygons used (polygon NDVI), vertical bars indicate the standard deviation.

The figure 3.4 shows the same data of figure 3.3, but without the values coming from satellite maps with highest clouds presence.



Graph 3.4 average NDVI values for each day, for animals locations (positions NDVI), buffer random points (Buffer NDVI), and the average of the daily polygons used (polygon NDVI), after the exclusion of dates with high clouds presence. Vertical bars indicate SD.

the differences after the correction to TOA reflectance of the bands are shown in graph 3.5 and we can see that all the values increase.

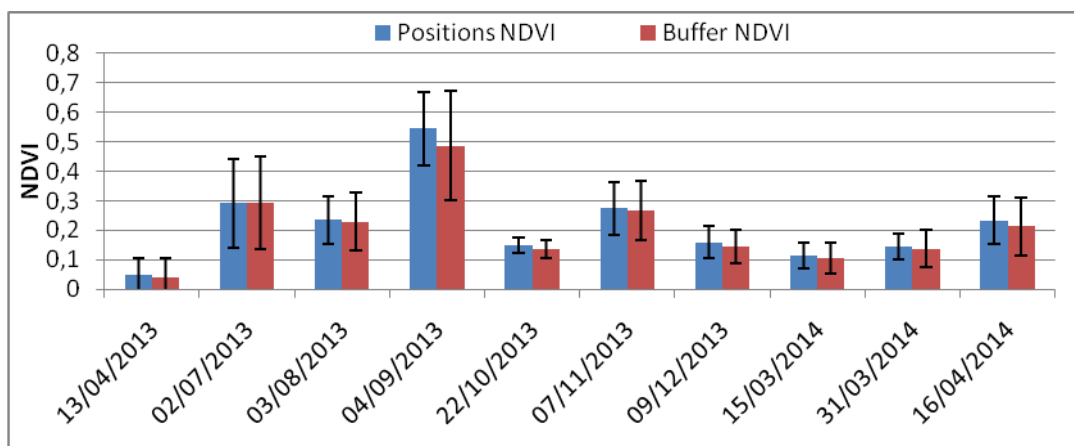


Fig. 3.5: NDVI values over time without the data corrected from the maps where clouds affected the results.

The values show a remarkable variability, but what is more interesting is that there are only minor differences between the position NDVI, the buffer NDVI, and the polygon NDVI, which would suggest the lack of any selection by the animals for higher NDVI values. In fact, although there can be a general tendency for the NDVI values of positions to be slightly higher than the others, the individual variability is much larger than these differences. However, many dates have very low NDVI values, under 0.2, that would imply the lack of vegetation. This can be related to two factors: the use by the ibex females of land use categories that are inherently without or very poor of vegetation, such as screes and rocks, and/or the presence of snow cover.

To address these questions, I compared the land covers use (proportion of locations within each land cover category) and availability (proportional surface of each land cover category in the polygons), grouping dates into summer (May-November) or winter (December-April). The results (figure 3.6) suggest that the animals of this sample did not select for any land cover class, since in both seasons the proportional use and availability values resulted similar. To this purpose, in addition, it is remarkable that the highest values of use and availability are for land cover classes with no or little vegetation (rocks and scree account for more than 70% of use and availability in both seasons).

Therefore, I decided to test a comparison between the NDVI values of the locations and those of the area available, only for the land cover categories with vegetation. To do so, first I divided the NDVI into different classes:

- Class 1: $NDVI \leq 0$
- Class 2: $0 < NDVI < 0,2$
- Class 3: $0,2 < NDVI < 0,4$
- Class 4: $NDVI > 0,4$

Then I extracted, from each polygon, the pixels with vegetation (grassland, forest and shrub), and calculated the distribution in NDVI classes of these pixels. Similarly, I extracted the locations in vegetated pixels and calculated their distribution into NDVI classes. Then, I calculated a selection index as the ratio between use and availability. The results are shown in figures 3.7 and 3.8. A first comment is that the sample size obviously decreased, and therefore the dates with an acceptable number of locations are less than in the above comparisons. With this caution, it is possible to see that the proportion of use tends to be

lower than that of the available for the 0-0.2 NDVI class, but higher for the 0.2-0.4 class, suggesting that there might be an avoidance of lower NDVI class and a positive selection for the higher one; the class >0.4 was present in only one date, and no reliable indications can be obtained from this single date. The selection indices, consequently, show values higher than 1 (preference) for the 0.2-0.4 class, and lower than 1 (avoidance) for the 0-0.2 class. This result is not supported by a robust statistic testing, due to the small size of the sample, but suggests a pattern that should be further investigated with a longer time series and a larger number of individual/locations.

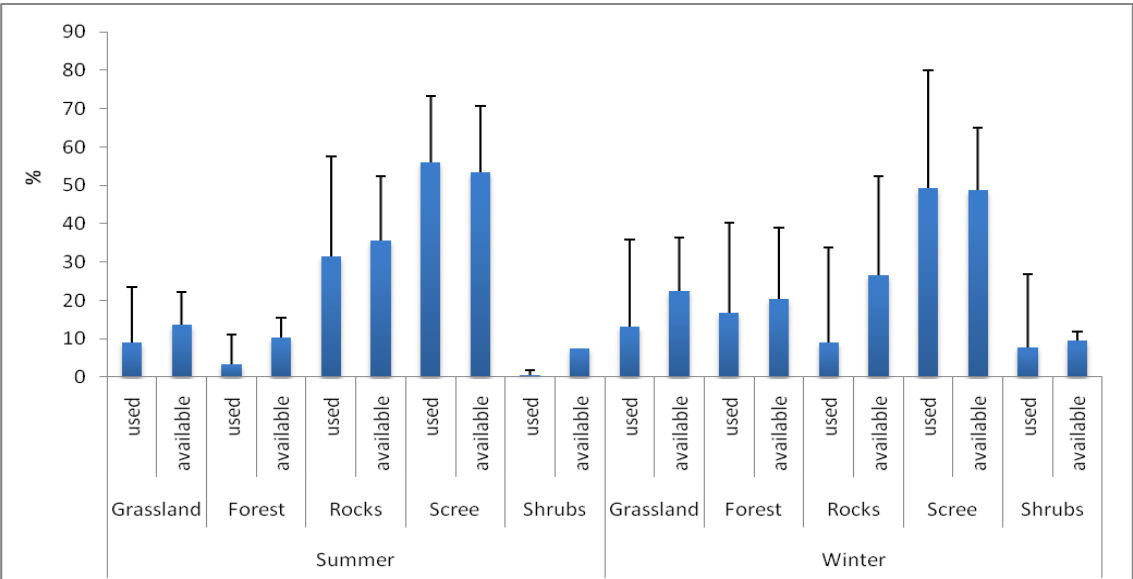


Fig. 3.6: percentage of land use used and available for each habit and seasons.

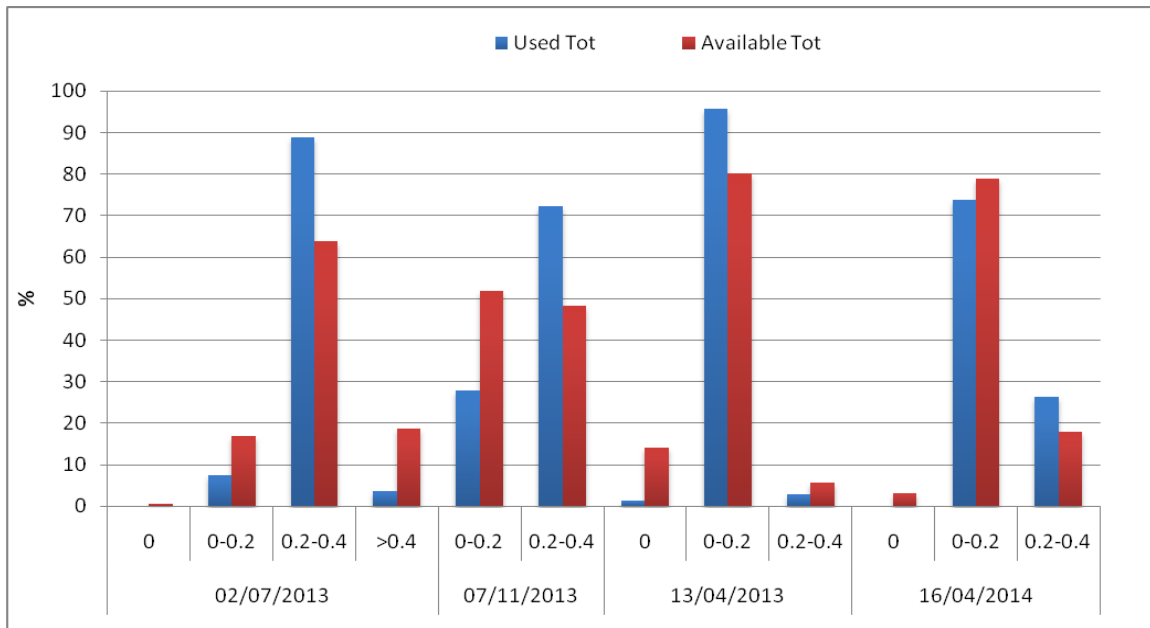


Fig. 3.7: total used and available habitat for NDVI classes.

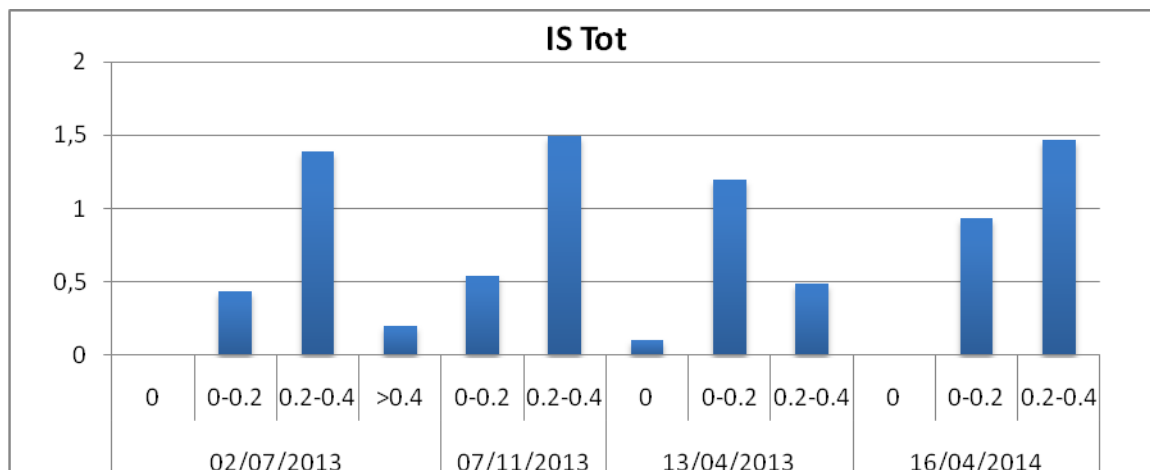


Fig. 3.8: Index Selection of the NDVI used and available.

4. Conclusions

This study has addressed the relationships between NDVI and the movement ecology and habitat selection of Alpine ibex, which is a species that lives in habitats often covered by scarce or even very low vegetation, where in addition the snow cover may last for long periods.

The spatial scale of NDVI estimated was very detailed (30 m pixels), but this has introduced a number of practical difficulties such as the more impacting presence of clouds on NDVI estimates at such scale, the variability in land use introduces the need for distinguishing between areas with vegetation and areas without, although this is not always easy. This is an important difference with the studies conducted on species living in more homogeneously vegetation covered areas (Nathalie Pettorelli et al., 2005; Nathalie Pettorelli et al., 2006).

Another problem is that L8 satellite starts to work only in the 2013, this has reduced the number of days/season available, and hence the final sample size.

Therefore, the results of this study are far from conclusive, although they suggest that, when land cover is taken into account into the analysis, a positive relationship between NDVI values and selection of patches with vegetation (in this study, essentially open forest or alpine grassland) might be actually existing.

There is therefore a need for further analyses with a larger samples size of locations in areas with vegetation, to support this hypothesis. Excluding winter, maps are no more than 16-18/year, and some of them may be unusable because of clouds. This might require either a large number of individuals monitored (many positions for few dates), or a long time (less positions but more dates). In alternative, since positions are collected hourly, the possibility of interpolating the NDVI temporal pattern of each pixel might be evaluated.

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