# DETECTION AND MAPPING OF INCIDENCE OF *VISCUM ALBUM* IN *PINUS SYLVESTRIS* FOREST OF SOUTHERN FRENCH ALPE USING SATELLITE AND AIRBORNE OPTICAL IMAGERY

THAPA, SUNIL
February, 2013

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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.

Specialization: Natural Resource Management

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# ABSTRACT

Increasing incidence rate of *Viscum album* in *Pinus sylvestris* is one of the major problems in the conservation and sustainability of *Pinus sylvestris* forest in the Alps. Mostly plantated forests are highly susceptible to biological invasion as compared to natural forests. The study area covered with coniferous plantation (mostly *Pinus sylvestris* in lower elevation), a part of Bois noir in the South Western French Alps is highly affected by semi-parasites *Viscum album*. Consequences like swelling of the branch, bending of tree structure; tree mortality of *Pinus sylvestris* is in alarming rate in the study area due to *Viscum album* incidence. For the management and minimization of the biological invasion, detection and mapping plays a key role in the forest conservation.

Detection and mapping of a biological invasion through remote sensing is a challenge to researchers to overcome these issues. Advancement of very high resolution (VHR) satellite imagery and aerial imagery with application of remote sensing and GIS technologies has shown a promising result in the detection, mapping and monitoring of the forest health. In this research digital aerial Ortho imagery (15cm resolution) and VHR satellite imagery WorldView-2 (panchromatic 0.5m and multispectral 2m) was used to detect and map the presence of *Viscum album* in the *Pinus sylvestris* forest by pixel based maximum likelihood classifier.

Distribution of *Pinus sylvestris* forest was successfully mapped with higher accuracy (96%) and kappa coefficient of 0.84 on WorldView-2 optical imagery. *Pinus sylvestris* in presence of *Viscum album* have low spectral reflectance in all bands however NIR1, NIR2 and red edge of WorldView-2 have the higher ability to discriminate the *Viscum album.* Similarly, the vegetation index NDVI 85 (band combination of red and NIR2) has the potential to discriminate the *Viscum album.* Furthermore, the results indicated that the *Viscum album* has a negative correlation and significant relationship ($r=-0.5135$; $p<0.01$) with the elevation whereas a significant positive relationship ($r=0.52$; $p<0.01$) with DBH of *Pinus sylvestris*. Weak but statistically significant multiple regression and a logistic regression was developed by using elevation and DBH to model the incidence of *Viscum album* in *Pinus sylvestris* trees.

Overall classification accuracy (86%) and kappa coefficient (0.52) was achieved in WorldView-2 image by applying pixel based maximum likelihood algorithm for the detection of *Viscum album* in *Pinus sylvestris* forest. A comparison of the 2m resolution WV-2 and 0.15cm resolution orthophoto classification outputs shows that the WV-2 imagery of lower spatial but higher spectral resolution gave a moderate higher (86%) classification accuracy.

The study reveals the high potential of high resolution optical imagery for detection and mapping tree infestation. Detection and mapping of such a biological invasion serves good information for the better management of the forest.

Keywords: Detection and mapping, *Pinus sylvestris*, *Viscum album*, Optical imagery, Biological invasion

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Sunil Thapa (February, 2013)
Enschede, the Netherlands

*...IN LOVING MEMORY OF MY LATE GRANDMOTHER SARASWOTI THAPA*

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# 1. INTRODUCTION

## 1.1. *Pinus sylvestris* (Scots pine)

*Pinus sylvestris (L.)* commonly known as Scots pine or Scotch pine, a highly diverse species (Xenakis et al., 2012) found from sea level to 2440m and ranges from Montane forests to Steppe (Cregg & Zhang, 2001). It's distribution extends from 2700km in north to south and 14,000km in east to west across Asia and Europe (Roche et al., 2009) and covers 28 million hectares of forests in Europe (Vacchiano et al., 2008). *Pinus sylvestris* can grow up to 36m high and can have wide range of mature growth form (Trees for Life, 2012). It is a light demanding and a stress tolerant species (Richardson, 1998), prefers sandy and loamy soils and can survive long in drought conditions. It can live nearly 1,000 years and 200 to 400 years of ages are normal (Jones, 1945). However its growth rates are reduced in alkaline soil and seedling growth is optimum in acidic soil (Carter 1987).

Photo 1: *Pinus sylvestris* forest

*Pinus sylvestris* plays a vital role in the diversity of the forest and is one of the major plant species on which many other species depend. *Pinus sylvestris* holds significant aesthetic natural, medicinal, timber, commercial and ornamental values. It is a keystone species and has relationships with various flora and fauna (Trees for Life, 2012). *Pinus sylvestris* has a direct and indirect role of host species for many plants, insects, birds and animals. For instance Scottish crossbill (*Loxia scotica*), endemic bird of UK is confined to the pinewoods (Trees for Life, 2012). It also plays a significant role in controlling rocks slides, landslides, erosion, windbreaks (Dobbertin et al., 2005a; Vacchiano et al., 2008).

## 1.2. *Viscum album* (Mistletoe)

*Viscum album austriacum* commonly known as mistletoe is a "mostly globose perennial evergreen shrub with persistent haustoria in the host" (Zuber, 2004b). *Viscum album* has a wide range of distribution in Asia and Europe (Hawksworth & Scharpf, 1986) "extends from 10° W to 80 E ad from about 60° N (max 59° 38' N) to 35° S" Zuber (2004a). There are four subspecies of *Viscum album* in Europe with varied host species (Zuber, 2008) . Furthermore, Barney et al. (1998) pointed that *Viscum album* have at least 452 plant species as its host species. *Viscum album* fully depends on their host tree for water and nutrients. They are hemi-parasites (Watson, 2001) for which the transpiration rates and stomatal conductance is higher whereas leaf water potential is lower than host species. However, *Viscum album* has its own functional chlorophyll (Tsopelas et al., 2004) and partially assimilate their own carbon by photosynthesis (Zweifel et al., 2012). Normal years for starting of sexual reproduction is at five years and


Photo 2: Fruit of *Viscum album* (courtesy: Dr. Hein van Gils)

March to April (Wallden, 1961; Zuber, 2008) is the main seasonal time for the flowering of *Viscum album*. Host habitat, size and canopy characteristics govern the incidence of *Viscum album* and it can grow at an average temperature above 15°c to -8°c in warmest and coldest month respectively (Dawson et al., 1990; Zuber, 2004b). Wind and birds are the main key agents for its pollination and dispersal of seeds. Life cycle of *Viscum album* is shown in appendix 2. *Viscum album* is useful in many ways. It is extensively used in the treatment of various illnesses like hypertension, diabetes, anthrosis and cancer (Amer et al., 2012). It provides food for various birds and often animals (Watson, 2001).

### 1.3. Overview of *Viscum album* impact on plant species

Why *Viscum album* is a threat to host species?

*Viscum album* has been a threat to its host species and infestation is growing widely in various forests exacerbating loss of tree species. Similarly, *Viscum album* severely affects the forest, ornamental tree species and orchards in a large extent (Varga et al., 2012). It has been one of the destructive agents for the various plant species. By extracting water and carbohydrate from their hosts *Viscum album* lead to water and nutrient deficiency (Dobbertin et al., 2005a; Rigling et al., 2010; Varga et al., 2012; Zuber, 2004b). During the drought period, *Viscum album* effect can be severe to host species as it increases the risk of drought induced mortality of its host species (Rigling et al., 2010). "*Viscum album* shows much higher transpiration rates and lower water potential than the host trees" (Rigling et al., 2010). Eventually it disrupts the stomatal system including gas exchange effect of the host plant (Zweifel et al., 2012) and thus reducing the photosynthesis phenomenon of the host species (Glatzel & Geils, 2009)

Photo 3: Heavy presence of *Viscum album* in popular trees (courtesy: Dr. Hein van Gils)

*Viscum album* has been widely distributed in the Alps and dry inner alpine valleys to Bavaria north of the Alps of Europe and has contributed to the decline of pine trees in the forest of Terul (Eastern Spain), Swiss national forest, Germany, Austria, Italy, Greece, Sweden, Great Britain (Dobbertin & Rigling, 2006; Oberhuber, 2001; Peršoh et al., 2010; Sanguesa-Barreda et al., 2012; Tsopelas et al., 2004; Vertui & Tagliaferro, 1998; Zuber, 2004b). Similarly, in Mexican cold mountain forest (evergreen coniferous forest), *Viscum album* is the second most destructive pest after the bark beetle (Clark-Tapia et al., 2011) . In evergreen coniferous forests of Croatia *Viscum album* has affected *Abies alba* (silver fir) in a large extent. A research by Idzojtic et al. (2008) has shown that a high correlation exists between the death rate of *Abies alba* and presence of *Viscum album* . Similarly, in Greece , tree mortality was highly correlated with *Viscum album* infection and 68% of the over storey trees were infected in fir (evergreen coniferous )forest of Mount Parnis (Tsopelas et al., 2004). Various researches have shown that *Viscum album* infestation is highly associated with higher crown transparency and can be considered as a bio-indicator for tree mortality. According to Varga et al. (2012) huge range of wood species have been infected by *Viscum album* and it has adversely affected their crown coverage, height and growth rate of the host. In South-western French Alps, the tree mortality of planted *Pinus nigra* is also in an alarming rate due to *Viscum album* (Vallauri et al., 2002).

## 1.4. *Viscum album* impact on *Pinus sylvestris*

*Pinus sylvestris* has been widely affected by *Viscum album* and is one of the major causes for its mortality. *Viscum album* incidence on *Pinus* species is mainly on Dicrano-Pinion, Erico-Pinion and Ononido-Pinion communities (Zuber, 2004b). Crown degradation, ramification and radial increments are some of the impacts caused by the pine *Viscum album* to the host *Pinus sylvestris* (Rigling et al., 2010). The mortality rate of *Pinus sylvestris* infested by *Viscum album* is twice higher than that of non-infested trees (Dobbertin & Rigling, 2006). In several studies it was found that the *Viscum album* infestation is also highly correlated with crown transparency (Dobbertin & Rigling, 2006) and can be considered as one of the bio-indicator of plant species damage and mortality in coniferous forests. Swellings, bending of tree structure, defoliation are some of the impact which can be visually assessed in the *Pinus sylvestris* with *Viscum album.* Furthermore, *Viscum album* considered as an indicator species for changes in temperature and since it extracts the water, it leads to drought stress for the host (Dobbertin et al., 2005b). High mortality rate of *Pinus sylvestris* due to effect of *Viscum album* has also been observed in the pine forest of Rhone valley of Switzerland (Dobbertin & Rigling, 2006). Distribution pattern of *Pinus sylvestris* and *Viscum album* in Europe including study area is shown in figure1.


Photo 4: *Viscum album* in branch of *Pinus sylvestris* in study area Barcelonnette

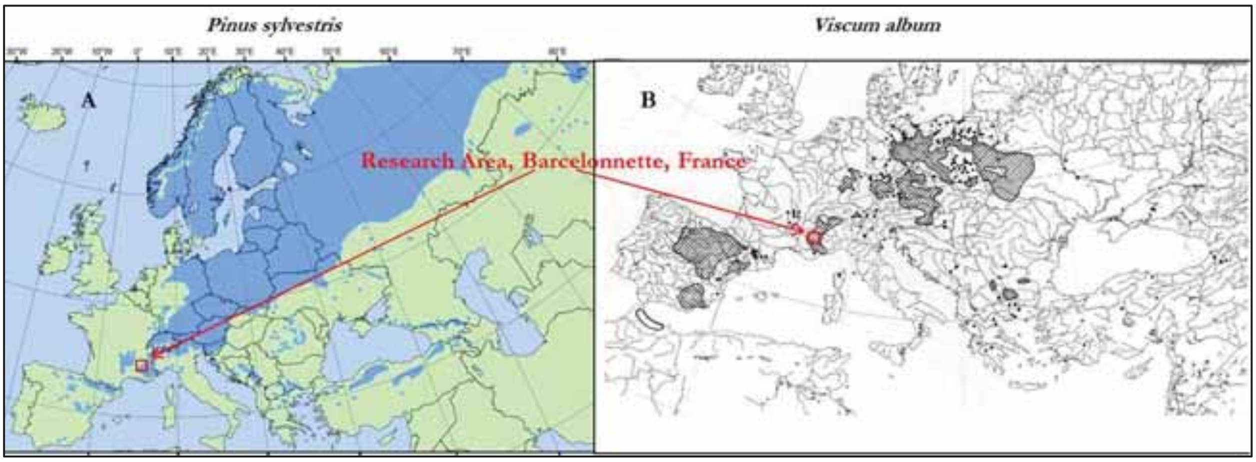


Figure 1: Distribution of (A) *Pinus sylvestris* and (B) *Viscum album* in Europe
[Source: A-(EUFORGEN, 2009) and B-(Zuber, 2004b)]

## *1.5.* Application of remote sensing for tree species classification and pest detection in forestry

Remote sensing tools and technologies have been widely used in forestry. Remote sensing is an effective tool for detection, monitoring and mapping of forest health, pest and biological invasive species in forest (Ismail et al., 2007; Joshi et al., 2006). Advancement of high spatial resolution aerial digital imagery (Ortho photo) and satellite imagery has gained importance in accurately assessing and monitoring the health status of the forest. Twenty first century digital aerial imagery has the potential to capture the image at 5 cm spatial resolution and 1 m pixel size (Wulder et al., 2012) and the very high resolution satellite sensors have the ability to take imagery of spatial resolution 50 cm for panchromatic and 2 m for multispectral. Very detailed tree stand level data can be achieved through high resolution digital aerial and satellite imagery

(Wulder, 1998; Wulder et al., 2006). According to Hussin et al. (2006) besides high spatial resolution, aerial images (TETRACAM) can show similar spectral characteristics as satellite (IKONOS) imagery can provide. However, both sensors (airborne and satellite) have their unique potential in the classification and monitoring of the forest.

Classification and identification of species is in high priority for the conservation and management of forests. Each plant has a unique spectral reflectance and with the development of remote sensing technology and high resolution imageries, it is possible to classify the species with good accuracy (Buddenbaum et al., 2005; Haara & Haarala, 2002; Leckie et al., 2003). Naydenova and Jelev (2009) got the overall classification accuracy of 92% for classifying seven land cover classes using very high spatial resolution aerial photos and satellite images. Dottavio and Williams (1983) were able to delineate heavy defoliation caused by gypsy moth at 88 % accuracy level using Landsat MSS. However, lower accuracies of 65% and 57% were documented for moderate defoliated and non-defoliated hardwood forests in Pennsylvania respectively. Canopy reflectance plays a vital role in the classification of the species. The tree crown is essential when classifying trees from remotely sensed data as its structure and the stand canopy affect the light interceptions which ultimately affect the growth of the tree (Oker-Blom et al., 1986). Moreover, Coops et al. (2006) used high spatial resolution remotely sensed data for the analysis and detection of tree crowns in evergreen coniferous forests subjected to stress and infestation. Furthermore, high spatial resolution multispectral data are capable to detect and map the pest attack with high accuracy (Wulder et al., 2006). Vegetation indices like NDVI (Normalized Difference Vegetation Index) and RGI (Red Green Vegetation Index) could separate the pest attack crowns (red attack) and non-attack crowns (Coops et al., 2006).

### 1.5.1. Use of spectral reflectance and vegetation indices in monitoring plant health

Spectral reflectance and vegetation indices are the key indicators used for assessing and monitoring the health of the plant from remote sensing data. Spectral reflectance of each plant species has its own unique characteristics which vary with wavelength and can be observed in the spectral reflectance plot (Carter & Knapp, 2001). Same species can respond differently according to their health condition (Carter & Knapp, 2001; Xie et al., 2008). “A spectral Vegetation index (VI) is usually a single number derived from the reflectance of two or more wavebands” (Ji & Peters, 2007). Vegetation indices are dimensionless radiometric measures which are computed from reflectance values and widely used to assess the health status of the plant species (Jackson & Huete, 1991). Normalized difference vegetation index (NDVI) is one of the most intensively used spectral vegetation index to analyse the plant stress, biomass, plant health and crop production. NDVI is first used by Rouse et al. (1974), it is calculated on the basis of spectral reflectance in NIR and Red band of the spectrum.

Vegetation indices have played a key role in remote sensing based analysis for detecting, mapping and monitoring health status of various trees, forests and invasive plants. The main purpose of the vegetation indices is to enhance the vegetation reflectance/signal and lower the reflectance of other effects like soil and solar irradiance (Jackson & Huete, 1991). Several vegetation indices like NDVI, enhanced vegetation index (EVI) are widely used to assess the health status of plants. The study done by Falkenström and Ekstrand (2002) in an evergreen coniferous forest (Norway spruce and Scots pine) verifies that the analysis of spectral reflectance from high resolution satellite data were able to detect pine defoliation in the near infrared (NIR) band. Furthermore, “high NDVI values would be associated with increased photosynthetic activity and would serve as a useful proxy for identifying stressed trees” (Wulder et al., 2006). Though NDVI shows a greenness (chlorophyll) contents, it gets saturated at high biomass however

EVI may address these issues. Wang et al. (2005) emphasized that "EVI is an optimized vegetation index with improved sensitivity in high biomass regions and an improved vegetation monitoring characteristics via a decoupling of the canopy background signal and a reduction in atmospheric influences". Since the use of red edge in spectral bands, the remote sensing technology has been able to monitor the health status of forest. According to Eitel et al. (2011), red edge plays a crucial role in detecting the stress in plants. The research done on the deciduous broadleaf forest shows that NDVI provides better result in low density canopy whereas EVI provides more accurate result in high density canopy (Ji & Peters, 2007).

### 1.6. Problem statement and justification

Increasing mortality of tree species due to pest infestation is one of the major issues in the conservation and sustainability of the forest. Study of these infected tree species has always intrigued researchers. In the study area (Bois noir catchment, Barcelonnette) *Pinus sylvestris* as one of the important tree species, is affected by *Viscum album* in an alarming rate. *Viscum album* impact has been seen only in *Pinus sylvestris* in the study area.

Conventional approach of fieldwork takes a considerable amount of time and cost. Use of current remote sensing technologies has provided improvements in conventional approaches for field data collection. From coarse resolution satellite data such as Advanced Very High resolution Radiometer (AVHRR) and SPOT VEGETATION to medium resolution imagery (Landsat, Aster or SPOT), are commonly used applications to detect and monitor insect-induced forest disturbances (Blanco et al., 2009; Breshears et al., 2005; Kharuk et al., 2004).

Measuring spectral reflectance is one of the methods to distinguish the tree species and it helps to identify the spectral signatures of species. The study area contains coniferous plantation forest with few dominant species and may provide higher classification accuracy. According to Holmgren and Persson (2004), it is possible to detect and distinguish coniferous trees from deciduous trees using near infrared imagery. In addition to this, foliage colour, crown apex, foliage texture, normalized difference vegetation index (NDVI), enhanced vegetation index (EVI) and leaf area index (LAI) are the key variables to identify and detect the health status of tree species. Changes in these indexes will help to assess the health status of the tree species (Coops et al., 2004; Ismail et al., 2008; Leckie et al., 2004).

The WorldView-2 (WV-2) satellite is the first high resolution commercial satellite with 8 spectral bands (Digital Globe, 2009). It has the spectral diversity of 4 standard colours (Blue, Green, Red and NIR1) and 4 new colours (Coastal, Yellow, Red Edge and NIR2). The multispectral resolution of this imagery is 1.85 m and it can provide 46 cm panchromatic resolution (Digital Globe, 2009). For the study of vegetation, Yellow, Red edge and Near infrared band plays a crucial role and as a Digital Globe (2009) red edge and NIR able to detect plant stress prominently (Adams et al., 1999). Previous research shows that vegetation indices were good parameters to assess the health status of trees and forest (Leckie et al., 2004; Stone & Coops, 2004). Furthermore, "Red Edge based remote sensing analyses were shown to be effective at identifying trees that were impacted by disease, and were able to provide quantitative information on the health of the trees" (Digital Globe, 2009) . Falkenström and Ekstrand (2002) study in evergreen coniferous forest in *Picea abies* (Norway Spruce) and *Pinus sylvestris* verified that, the spectral reflectance from high resolution satellite data can provide pine defoliation in NIR band and also established strong relationship between the ratios of NIR & Red, and NDVI.

The research done by Astola et al. (2006) in the boreal forest (evergreen coniferous) of *Pinus sylvestris* and *Picea abies* in Eastern Finland shows that, around 88% of trees were correctly classified on the basis of spectral reflectance by using high resolution multispectral imagery (IKONOS). Bhattarai et al. (2011) also found that among several vegetation indices, spectral response of NDVI obtained from WV-2 image is able to classify the *Pinus sylvestris* infested by *Sirex* woodwasp. In evergreen broadleaf forest, the classification done on the basis of spectral signature separability and object based image analysis using very high resolution satellite imagery obtained a good accuracy and were able to improve the change detection in species (Chen et al., 2012). Maximum likelihood classifier (MLC) is one of the most commonly and widely used for classification. In MLC, "the decision rule is defined by the multidimensional normal distribution around a class mean" (Liu et al., 2000). The research by Hicke and Logan (2009) got the overall accuracy of 86% and kappa statistics of 0.82 for mapping white-bark pine mortality caused by a mountain pine beetle by using MLC on high spatial resolution satellite imagery. In crop identification, Yang et al. (2011) was able to obtain high accuracy of 91% by applying the MLC method.

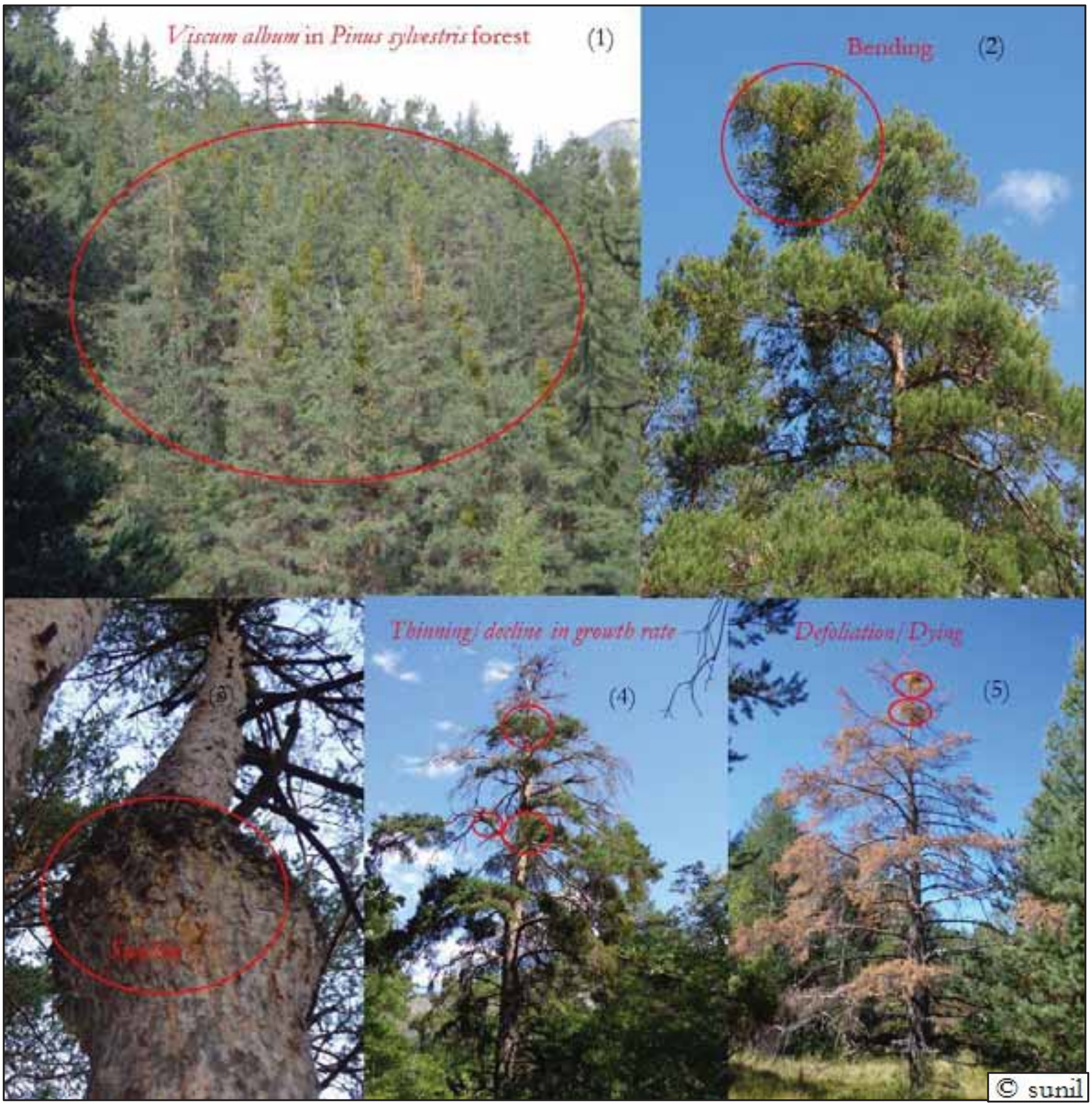


Photo 5: Impact of *Viscum album* in *Pinus sylvestris* trees in study area (Bois noir, Barcelonnette, France)

Pest infestation has been researched using remote sensing technologies; however use of WV-2 satellite imagery for detecting *Viscum album* infestation in *Pinus sylvestris* is yet to be studied. This research will help to analyse the possibility and performance of WV-2 for detecting incidence of *Viscum album* in *Pinus sylvestris* trees. The generated occurrence of *Viscum album* in *Pinus sylvestris* distribution forest map may have added value for the conservation and management of forest in study area.

## 1.7. Research objectives:

The overall goal of the research is to detect and map the presence of *Viscum album* in *Pinus sylvestris* forest using very high resolution satellite imagery (WV-2) and multispectral Ortho-photo of airborne digital camera.

### 1.7.1. Specific objectives:

1. To accurately classify the *Pinus sylvestris* forest using WV-2 image.
2. To study the spectral distinctness of *Pinus sylvestris* in the presence and absence of *Viscum album*.
3. To determine the relationship of presence of *Viscum album* in *Pinus sylvestris* with elevation and DBH.
4. To determine whether very high resolution multispectral imagery can detect the presence of *Viscum album* in *Pinus sylvestris*.

## 1.8. Research questions

1. Is *Pinus sylvestris* with and without *Viscum album* is spectrally distinct?
2. Can vegetation Indices (NDVI-with different band combination) derived from multispectral imagery (WV-2) differentiate the presence and absence of *Viscum album* in *Pinus sylvestris?*
3. Is there any significant relationship in incidence of *Viscum album* in *Pinus sylvestris* with elevation and DBH?
4. How accurately can the incidence of *Viscum album* in *Pinus sylvestris* forest be detected by the use of maximum likelihood classification (pixel based classification) on WV-2 satellite and Ortho imagery?

## 1.9. Hypothesis:

1. $H_1$: There is a significant difference in the spectral reflectance of *Pinus sylvestris* in the presence and absence of *Viscum album.*
   $H_2$: There is no significant difference in the vegetation indices of *Pinus sylvestris* in the presence and absence of *Viscum album*.
2. $H_1$: There is no significant difference in the incidence of *Viscum album* with elevation.
   $H_2$: High incidence of *Viscum album* in low elevation.
3. $H_1$: can be detected *Viscum album* in *Pinus sylvestris* forest with significant accuracy by applying pixel based MLC on high resolution imagery (WV-2).

## 1.10. Research innovation

The innovation of this research is aimed at detection of *Viscum album* in *Pinus sylvestris* tree by image classification on WV-2 satellite imagery which has not yet been done. This research will further add value in application of remote sensing and the use of high resolution imagery (WV-2) in detecting the *Viscum album* infestation in forest and will eventually help in forest conservation and management.

# 2. DESCRIPTION OF STUDY AREA

## 2.1. Background

Barcelonnette is a small municipality situated in the South Western French Alps. Barcelonnette is also known as the heart of the Ubaye Valley and a home for around 3500 people (www.barcelonnette.com). Sunny days, clear cold nights are the climatic features of the area. Barcelonnette is a major tourist attraction for the skiing, biking, hiking, paragliding and rafting.

## 2.2. Study Area

The study area is a part of Bois noir catchment (3 $km^{2}$) with the elevation ranges from 1100 to 3000 m. However, the core study area is 0.6 $km^2$ and located in south and east part of the catchment between 1402 to 1700 m. Location map of the study area is given in appendix 3.


Photo 6: Overview of the study area -Southern hills (Bois noir, Barcelonnette, France)

### 2.2.1. Climate

The climate of the study area is dry mountainous. Inter annual rainfall strongly varies from 400 mm to 1400 mm and the mean annual temperature is around 7.5°c (Maquaire et al., 2003).

### 2.2.2. Geology:

The area has an irregular rugged topography with slope gradients ranging from 10° and 35° and scree slopes (Saez et al., 2012; Thiery et al., 2007). The study area is covered by 15 m thick Morainic colluvium, underlain by autochtonous Callovo –Oxfordian black marls and both materials are highly sensitive to landslides (Maquaire et al., 2003). The area is highly landslides prone zone and mostly planted by pine trees in 19th century. Recently subject to multiple reactivations of landslides (Razak et al., 2011b) and a rotational slide is quite prominent (Saez et al., 2012).

### 2.2.3. Vegetation

The vegetation of the study area is a century old plantation of coniferous trees with pockets of broadleaf forest. In 18th and 19th century, the Bois noir area suffered from heavy deforestation (Kappes et al., 2011). To control deforestation and debris flow, reforestation and construction of check dams was initiated (Kappes et al., 2011). At present, 92% of area is covered by forest (Thiery et al., 2007). *Pinus sylvestris, Pinus uncinata, Picea abies* and *Larix decidua* Miller are the major tree species. These plantations are also in the abandoned agricultural fields and the evidence of remnants of terraced crop farming has been observed. According to Saez et al. (2012) average mean age of trees in the Bois noir catchment is of 100 years. High and frequent landslide activities in the Bois noir catchment has disrupted the tree stand structures often known as "drunken trees" (Razak et al., 2011a). Species identification and its description were recorded from Dr. Hein A.M.J. van Gils (2011, 2012).

Photo 7: Deforestation (1905 AD)

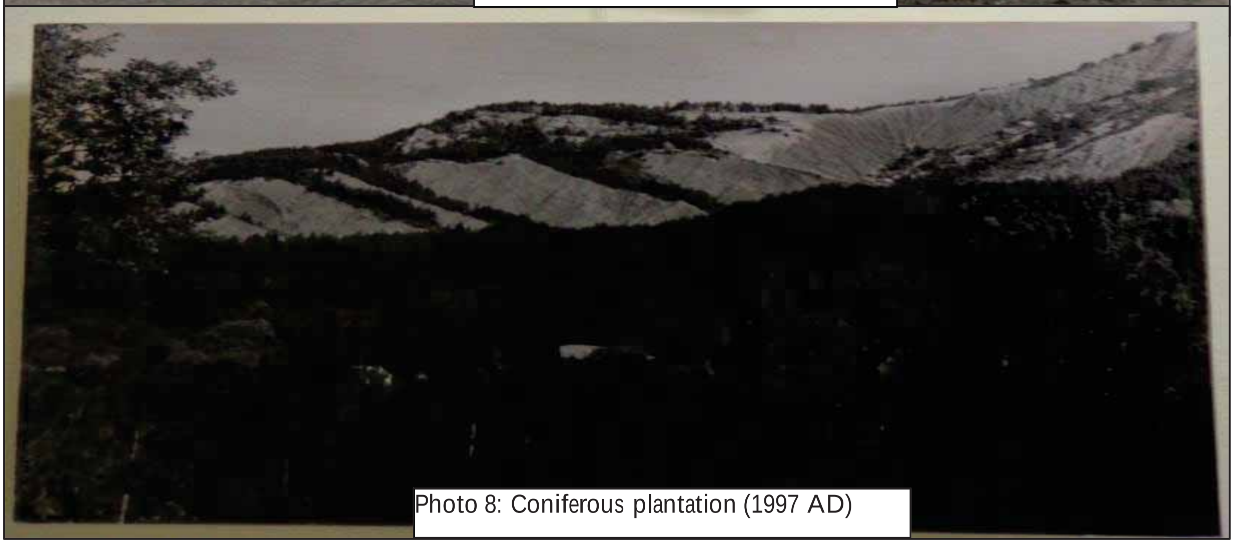

Photo 8: Coniferous plantation (1997 AD)

(Source: Photo 6 & 7 -Chaudon Norante,)

#### 2.2.3.1. *Pinus sylvestris* L. (Le Pin sylvestre):

*Pinus sylvestris* is an indigenous species in the dry inner alpine valleys and the dry Alps, distribution shown in figure 1. *Pinus sylvestris* have their own cuticle illustration of needles and stomata which clearly distinguished (Fauvart et al., 2012) from other coniferous species like mountain pine (*Pinus uncinata)*. The upper half of the stem is flaky and orange in color whereas the lower scaly dark grey brown color and the cones are symmetrical with an umbo cantered. Some of the patches of *Pinus sylvestris* tree structures are highly disrupted. This may be due to active and frequent landslides in the study area.

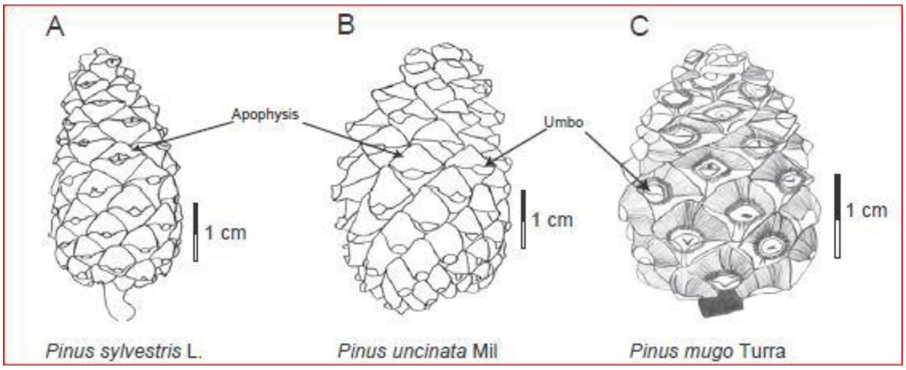


Figure 2: Physical structure of cones of *Pinus sylvestris, Pinus uncinata* and *Pinus mugo*

[Source: (Fauvart et al., 2012)]

2.2.3.2. Mountain pine *[Pinus uncinata* Mill. ex Mirb. (Le Pin a crochet)]:

*Pinus uncinata* is also called Swiss Mountain pine which naturally found at the tree line, in Pyrenees and the Western Alps. It is sometime conisdered a sub species of *Pinus mugo* and aslo found in the central to Eastern Alps, the Balkan and Apennins. Its cones are assymetrical and have a hook-shaped umbo with much thicker scales on one side of the cone which makes it distinguished from other conferous trees. *Pinus uncinata* can grow from 12 to 20 m tall. *Pinus uncinata* also has been used in France for land rehabilitation and controlling of landslides. In research area, *Pinus uncinata* trees age varies from 60 to 80 years and are younger compared to other tree species (Saez et al., 2012). High numbers of disrupted *Pinus uncinata* (drunken trees) are found in the upper part of the study area.

2.2.3.3. *Larix decidua* Miller.:

*Larix decidua* commonly known as larch is a deciduous conferous tree. It is indigenous in the Alps, central Europe and Carpathians.The size of *Larix decidua* varies but can grow up to 45 m tall.

2.2.3.4. *Picea abies* L. (Karsten):

*Picea abies*, an evergreen coniferous trees belongs to spruce species and is native to Europe. It is a fast growing species and can grow upto 55m tall. This species is also widely planted outside its native habitat.


Photo 8 : " Drunken" *Pinus sylvestris* trees


Photo 9 : " Drunken" *Pinus uncinata* trees

# 3. MATERIALS AND METHODS

## 3.1. Satellite data

Very high resolution satellite imagery (WV-2) of having 8 bands spectral resolution of 2m and panchromatic resolution of 0.5m was used for this study. The imagery was acquired in September 2010 and the metadata of this imagery is given in appendix 4.

## 3.2. Digital aerial Ortho image and LiDAR data

The aerial Ortho- photo and airborne LiDAR data acquired in July 2009 under snow free conditions were used. The dataset was initially collected for the study of landslides activities and the aerial ortho image having 15 cm resolution was also captured at the same time. Aerial Ortho image consists of 3 bands (red, green, blue). The LiDAR derived canopy height model (CHM) and digital terrain model (DTM) were used as explained in section 3.5.2 .

## 3.3. Field material

Following listed equipment were used to collect data for fieldwork.

Table 1. List of equipment

| SN | Equipment | Purpose |
|---|---|---|
| 1 | iPAQ and Garmin GPS | Navigation |
| 2 | Leica differential GPS system 1200 | Recording spatial co-ordinates |
| 3 | Sunnto compass | Orientation |
| 4 | Diameter tape (5m) | Measurement of DBH |
| 5 | Measuring tape (50 m) | Measuring radius of circular plot and length of transect plot |
| 6 | Spherical densitometer | Measuring canopy density |
| 7 | Fieldwork datasheet | Field data record |

## 3.4. Processing Software

Following listed software were used for this research.

Table 2. List of software and its purpose of usage

| SN | Software | Purpose of Usage |
|---|---|---|
| 1 | ArcGIS2010 | GIS Analysis |
| 2 | Erdas Imagine 2011 and ENVI 4.7.2 | Image Processing |
| 3 | SPSS and R | Statistical Analysis |
| 4 | Word, Excel, Powerpoint, End note and Visio | Thesis Writing and editing |

## 3.5. Methods

The research methodology is shown in figure 4.

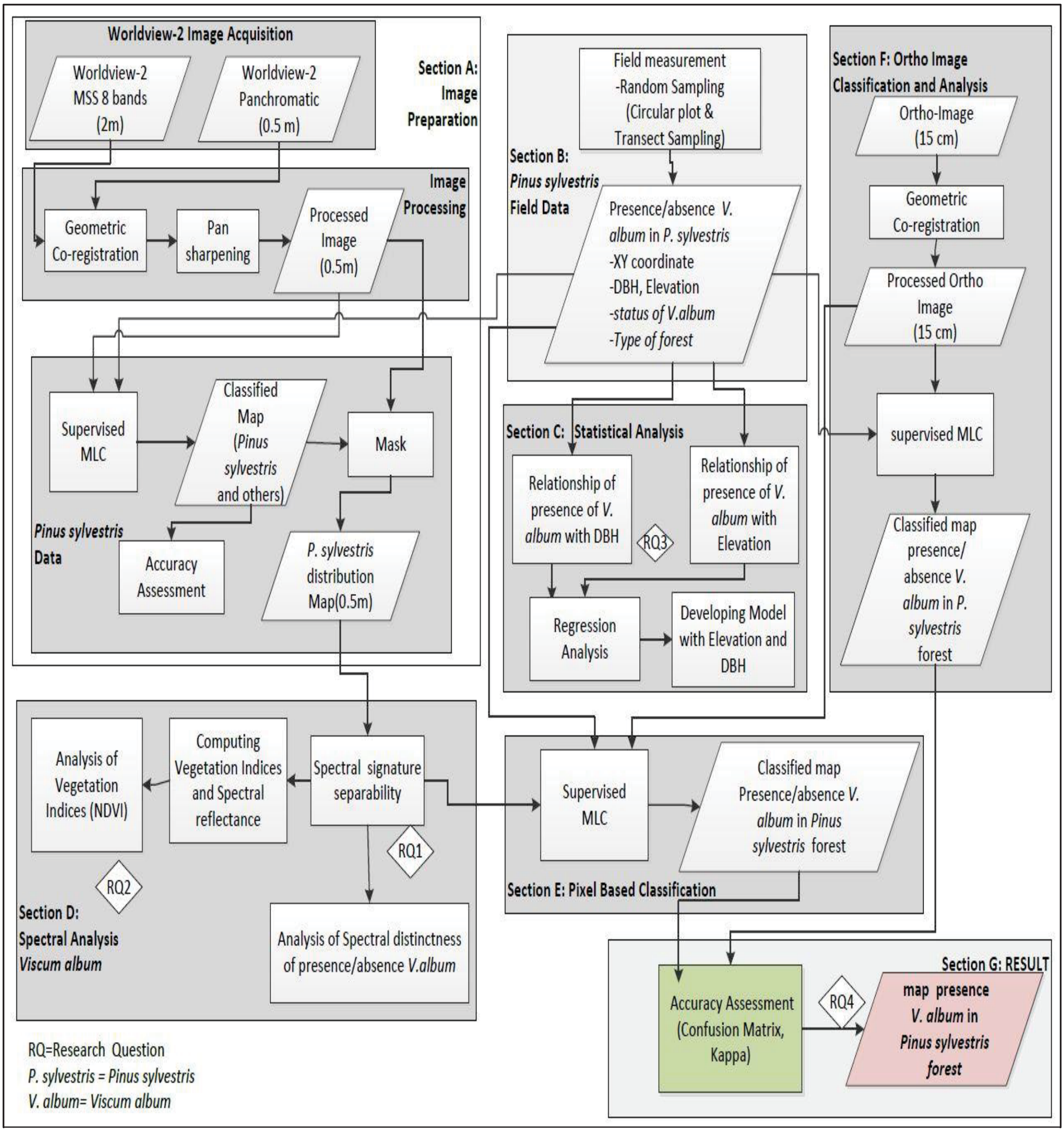


Figure 3: Flowchart of research

### 3.5.1. Sampling Design

The field sampling design was based on two methods. Circular plot and transect samplings were adopted for data collection in the field. To avoid bias, a random set of 40 location points were generated in the study area by using a GIS. Only 31 circular plots were surveyed. So as to increase the *Viscum album* incidence data 27 transects were sampled as further explained in section 3.5.2 on field techniques. Due to time limitations and topographic constraints 7 sample points were discarded and 2 plots without *Pinus sylvestris* trees were also removed from the sampling set.

Transect and circular sampling methods were applied due to following reasons:

- Circular plot were used to assess the forest structure parameters like tree density, abundance, frequency and species diversity analysis (Boakye et al., 2012).
- Circular plot has a minimum perimeter with no fixed orientation and easy to measure in the forest (Husch et al., 2003)
- Line transect method is widely used in forest data collection including biological invasion of forest (Günter et al., 2007; van Gils et al., 2004; van Gils et al., 2006) .
- Most of the statistical analysis was performed on the basis of circular plot data whereas transect data were added for training samples and used in accuracy assessment.

### 3.5.2. Field techniques:

Field data collection was carried out from 11th September to 27th of September 2012 during leaf on conditions. The iPAQ and Garmin GPS were used to navigate to the selected plot centre. However, due to canopy obstructions it was impossible to locate plot centres precisely. To minimize the error, the available LiDAR derived canopy height model (CHM) (Kumar, 2012) was used to determine the centre of the plot. Using the CHM, at least two landmark features were identified in the surroundings of centre plot as seen on the CHM to confirm plot centres. The centre point and individual locations of trees were subsequently determined by measuring the bearing and distance using the sunnto compass and measuring tape respectively. Differential Global Positioning System (DGPS) was also used to record the geographic coordinate of centre point of the plot.

From the centre, the circular plot having 500 $m^2$ areas was established to collect the data after slope correction (Husch et al., 2003) . Within a plot, all trees species were counted and *Pinus sylvestris* trees with diameter at breast height (DBH) greater than 3 cm were measured using a DBH tape. Each *Pinus sylvestris* tree in the plots were visually assessed on the ground and recorded the incidence of *Viscum album.* Crown coverage of the plot was measured using a spherical densiometer from five different locations within the plot and canopy cover was averaged. Photographs of each plot were taken at the same time in the field to recognize the trees in the WV-2 image and Ortho photo.

After sampling of a circular plot, four 50 m perpendicular line transects were laid from the same centre point. The presence (P) and absence (A) of *Viscum album* in *Pinus sylvestris* trees was recorded at 5 m intervals. The XY co-ordinate, type of forest and density of *Viscum album* of each *Pinus sylvestris* tree species was recorded and observed on the ground.

Density of *Viscum album* in *Pinus sylvestris* was given as follows:

| | |
|---|---|
| 0=No *Viscum album* | 1=Low *Viscum album* |
| 2=Medium *Viscum album* | 3=High *Viscum album* |

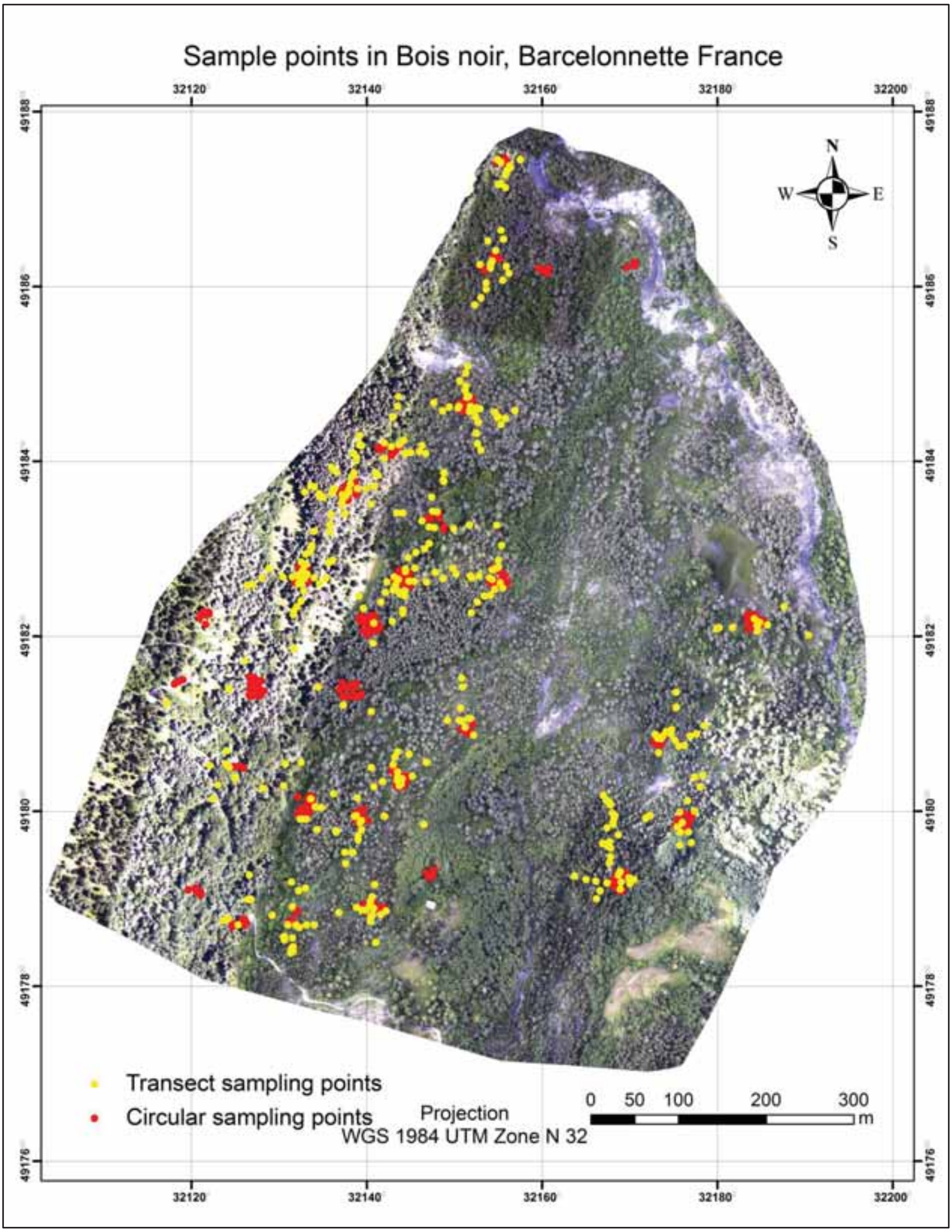


Figure 4: Field sample points locations in Ortho photo

## 3.6. Image pre-processing

The WorldView-2 (WV-2) image was delivered without any cloud cover, and both atmospherically and radiometrically corrected. The image was pre-processed in three stages; (i) geometric correction, (ii) pan sharpening and (ii) image enhancement.

### 3.6.1. Geometric correction

In the first stage, the aerial Ortho photo captured during the collection of LiDAR data was geo-referenced. However there was a challenge to match the high resolution WV-2 optical imagery with LiDAR derived CHM and aerial Ortho photo. This is due to differences in geometric properties. WV-2 rational polynomial coefficients model available in ERDAS© software was used to transform the image coordinates to earth surface coordinates. Rational Polynomial Coefficients (RPC) is an empirical mathematical model which is relating the image space to latitude, longitude and surface elevation.

In the second stage, six ground control points were used to improve the geometric precision between the optical imagery and provided LiDAR derived surfaces. Identical areas (house and corner of the road) in the optical and aerial images were tied in ERDAS LPS tools. Both panchromatic and multispectral WV-2 bands were shifted 12m with an average root mean square error of 1 pixel.

### 3.6.2. Image fusion and enhancement

WV-2 multispectral image of 2m resolution and 0.5m resolution of WV-2 panchromatic image were fused through HCS pan sharpening algorithm by using ERDAS© software as described by Padwick et al. (2010). This algorithm is specifically developed for WV-2 images and has the capability of maintaining the spatial and spectral recovery of all bands. For image enhancement, five different window filter size were applied. In HCS resolution merge it has the smoothing filters of five different sizes (3x3, 5x5, 7x7, 9x9 and 11x11) were applied on the image to cross check the image quality before finalizing the pan sharpened image. There was no significant difference in spectral and spatial quality of the five images obtained using different convolution filtering sizes. To choose the best pan sharpened image, the visual interpretation was applied and the image acquired through using the dimension of 7x7 convolution filter was chosen.

## 3.7. Fieldwork data analysis

Normality of the field data was checked. The descriptive statistical analysis (Husch et al., 2003; Zobel et al., 1985) of the field data was done. The tree and forest variables were viewed in histograms and whisker boxplots were prepared using R software to depict the presence and absence of *Viscum album* in *Pinus sylvestris* as with the elevation and DBH.

### 3.7.1. Vegetation analysis

The following parameters were calculated for the forest analysis.

$$Frequency\ (\%) = \frac{no.of\ sampling\ plots\ in\ which\ the\ species\ occurred}{Total\ no.of\ sampling\ plots} \times 100 \qquad \text{Equation (1)}$$

$$Density = \frac{Total\ no.of\ individual\ tree\ species\ in\ all\ sampling\ plots}{Total\ no.of\ sampling\ plots} \qquad \text{Equation (2)}$$

$$Relative\ Density\ (\%) = \frac{Density\ of\ a\ tree\ species}{Total\ density.of\ all\ tree\ species} \times 100 \qquad \text{Equation (3)}$$

$$Abundance = \frac{Total\ no.of\ individuals\ of\ a\ tree\ species\ in\ all\ sampling\ plots}{No.of\ sampling\ plot\ in\ which\ species\ occurred}$$ Equation (4)

$$Relative\ Abundance\ (\%) = \frac{Abundance\ of\ a\ tree\ species}{Total\ no.of\ all\ tree\ species} \times 100$$ Equation (5)

$$Basal\ Area\ (BA) = \Pi r2 = \frac{\Pi(\mathrm{DBH})2}{4} \times 100\ (\mathrm{cm}^2)$$ Equation (6)

Where, DBH = diameter of tree at breast height

### 3.7.2. Tree diversity analysis:

Shannon diversity index, species richness (no. of species) and species evenness (Magurran, 1988; Margalef, 1958; Shannon & Weaver, 1962) were calculated for each plot. The following equations were applied for the calculation of these indexes

Shannon Diversity Index (H'):

$$H' = -\sum \mathrm{pi} \times \ln \mathrm{pi}$$ Equation (7)

Where

pi = the proportion of individuals belonging to i$^{th}$ tree species

Species richness:

$$\text{Margalef's index} = \frac{(S-1)}{\ln N}$$ Equation (8)

Where,

S = total number of species

N = total number of individuals in the sample

Species Evenness:

$$\mathrm{e} = \frac{H}{\ln S}$$ Equation (9)

H = Shannon–Wiener diversity index

S = total number of species in the sample

### 3.7.3. Statistical analysis

The t-test, correlation analysis, ANOVA test and regression analysis were used. Field data of presence and absence of *Viscum album* was tested by t-test to determine the relationship with elevation and DBH. Furthermore, two models were developed using R software to estimate the presence of *Viscum album* in *Pinus sylvestris* by applying multiple regression and logistic regression method. Elevation and DBH were used as explanatory variables. The binomial logistic regression model was selected in this research. The dependent variable (presence and absence of *Viscum album*) are dichotomous and the independent variables (DBH and elevation) are used as predictors. A value 1 corresponds to the presence of *Viscum album* whereas a value 0 characterizes the absence of *Viscum album* in *Pinus sylvestris*. The model was performed by using R-statistical package.

The equations used for the model were as follows:

Multiple Regression:

$$y = b_0 + b_1 x_1 + b_2 x_2 \qquad \text{Equation (10)}$$

For Logistic regression:

$$P_x = \frac{e^{b_0+b_1x_1+b_2x_2}}{1+e^{b_0+b_1x_1+b_2x_2}} \qquad \text{Equation (11)}$$

Where, $b_0$ is slope intercepts and $b_1$ and $b_2$ are estimated parameters for DBH and elevation in both models.

#### 3.7.4. Image classification

At first the WV-2 image was classified into the major dominant tree species by applying supervised MLC through ERDAS© software. From this image, only *Pinus sylvestris* forests were extracted by masking in ArcGIS 10 software in both the processed WV-2 image and Ortho image. Following are the steps applied for this classification:

##### 3.7.4.1. Supervised pixel based maximum likelihood classification (MLC):

For decades, MLC has been a most widespread classification method in remote sensing. MLC is a statistical classification method which uses both the mean and centre of each class that relies on Gaussian distribution and a pixel with a maximum likelihood was considered as a same class (Kavzoglu & Reis, 2008). While assigning classes, both variance and covariance of the class signatures are considered. The field training data was used to collect a signature to classify the pixel as a presence and absence of *Viscum album* in pine tree/forest by using supervised MLC. The shapes, sizes, distance and locations are considered while assigning the pixels to each class and " if the assumption of a normal distribution for each class is correct then the classification has a minimum overall probability of error and the MLC is the optimal choice" (Kavzoglu & Reis, 2008).

Since the *Viscum album* is limited to *Pinus sylvestris* only three classes namely; (1) *Pinus sylvestris*, (2) broadleaf and (3) others were classified by applying supervised MLC algorithm through ERDAS© software. Five reference point (co-ordinates) for the class 'others' were manually picked from Ortho image to increase a sufficient number of reference point to test the classification accuracy. In the second stage, the *Pinus sylvestris* data obtained from the classification was exported using ArcGIS to create only *Pinus sylvestris* data. And both the images (WV-2 and Ortho image) were masked by acquired *Pinus sylvestris* data through ArcGIS software and the distribution map of *Pinus sylvestris* was generated.

#### 3.7.5. Extraction of canopy spectra of *Pinus sylvestris* in presence and absence of *Viscum album* from WV-2 image:

Training samples of presence and absence of *Viscum album* in *Pinus sylvestris* were obtained using field observations as a reference. Pixel value of sample *Pinus sylvestris* trees was extracted from the spectral profile and exported to excel sheet. ERDAS© software was applied for the extraction of canopy spectra. The mean pixel values (DN value) of *Pinus sylvestris* trees with and without *Viscum album* were plotted in Y axis and the eight spectral bands of WV-2 were plotted in the X-axis.

#### 3.7.6. Computing and analysis of spectral vegetation indices

Three equations using different band combinations for NDVI (Rouse et al., 1974) were computed (table 3) in the model maker of ERDAS© software. Three different NDVI maps were generated. Field points of presence and absence of *Viscum album* were overlaid on the three NDVI images. To extract pixel values from the NDVI images for spectral signature development an inquiry box of minimum of 6 pixels was used. The pixels values at the determined geographic location were exported to ASCII file. The mean value of those exported presence and absence of *Viscum album* in *Pinus sylvestris* was plotted in Excel and the analysis was carried out.

Table 3. NDVI Vegetation Indices

| S.N. | Abbreviation |
|---|---|
| 1 | NDVI 76 |
| 2 | NDVI 85 |
| 3 | NDVI 86 |

Where, 5= Band 5 (Red) 6= Band 6 (Red edge)
7= Band 7 (NIR1) 8= Band 8 (NIR2)
(*Note: Cross reference for wavelength range, see figure 22)

The two sample t-test was used to analyse the performance of each vegetation index for distinguishing the presence and absence of *Viscum album* in *Pinus sylvestris*. The performance of different vegetation indices to discriminate the presence and absence of *Viscum album* was compared using the Kruskal-Wallis test (Kruskal and Wallis, 1952). If the Kruskal-Wallis test indicated a significant difference, the Mann-Whitney U-test with Bonferroni correction was applied to account for the multiple comparisons among the different vegetation indices.

#### 3.7.7. Supervised pixel based maximum likelihood classification (MLC) of WV-2 and Ortho image:

In supervised classification it is necessary to know the spectral characteristics of each class to make a decision rule to classify the whole population. For the classification of presence and absence of *Viscum album* in *Pinus sylvestris*, once again supervised MLC was used in ERDAS© software and the distribution map of presence of *Viscum album* in *Pinus sylvestris* were generated.

### 3.8. Accuracy assessment:

The accuracy of all three classified map was assessed on the basis of a confusion matrix and Cohen's kappa statistic (Congalton, 1991). Confusion matrix is a specific table having the quantitative or statistical information regarding actual and predicted classifications obtained through the classification algorithm / system. Confusion matrix records the major four parameters (i) true positive, (ii) false positive, (iii) false negative and (iv) true negative (Allouche et al., 2006) to evaluate the classification accuracy.

Kappa statistics is the accuracy measurement methods which is based on the difference between observed agreement and expected agreement (Viera & Garrett, 2005). The kappa coefficient summarizes an agreement table (Sim & Wright, 2005; Warrens, 2011) and kappa coefficient value ranges from negative 1 to positive 1. Higher value signifies the better performance whereas lower value represents the poor performance. Negative 1 indicates a complete disagreement between observed and expected agreement whereas positive 1 signifies a prefect agreement. Landis and Koch (1977) assess the Cohen's value as excellent (kappa>0.75), fair to good (0.75>kappa>0.4) and poor (kappa<0.4).

Kappa statistics can be calculated as:

$$Kappa\ (k) = \frac{P_0 - P_e}{1 - P_e} \qquad \text{Equation (12)}$$

Where,

Po= Observed agreement
Pe= Expected agreement

The true skill statistic (TSS) of each classified image was also calculated to assess the accuracy of image classification. Even though the kappa is widely used in accuracy or model assessment, it has some shortcomings which are compensated by TSS measure (Allouche et al., 2006). The value of TSS also ranges from negative 1 to positive 1. The TSS is calculated as follows:

$$Sensitivity = \frac{No.\ of\ true\ presence}{(No.of\ true\ presence + No.of\ false\ absence)}$$ Equation (13)

$$Sepecificity = \frac{No.\ of\ true\ absence}{(No.of\ true\ absence + No.of\ false\ presence)}$$ Equation (14)

$$True\ skill\ statistcis\ (TSS) = Sensitivity + Specificity - 1$$ Equation (15)

# 4. RESULTS

## 4.1. Tree species in the forest

The study area is dominated by *Pinus sylvestris*. However seven other woody species were recorded. The proportion of *Pinus sylvestris* is more than 75% in 60% of the analysed plots. In 15% of plots the ratio of *Pinus sylvestris* species ranges from 30 to 60%. Broadleaf covers around 11% of the forest area and followed by mountain pine (*Pinus uncinata*) by 8% and *Alnus viridis* covers the least (0.5%).

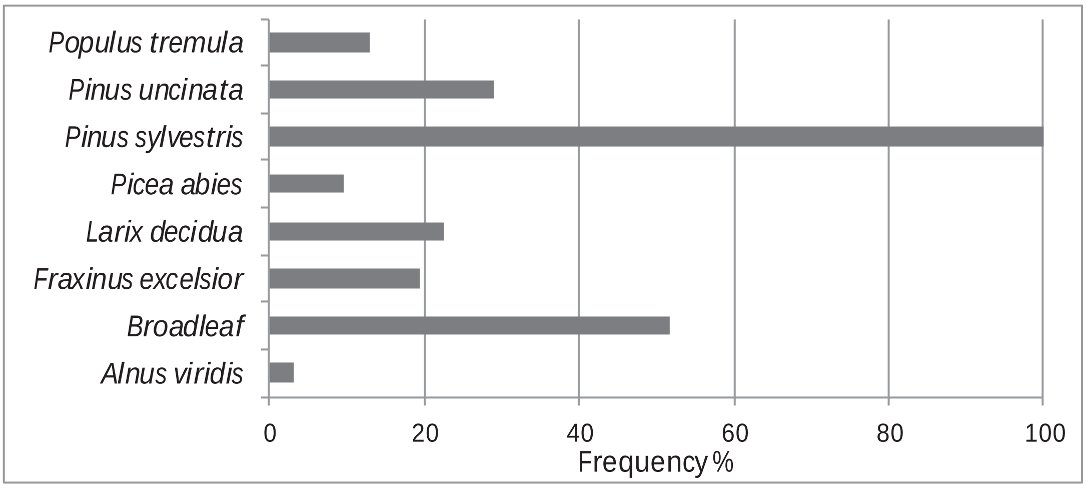


Figure 5: Frequency of tree species in sampled plot

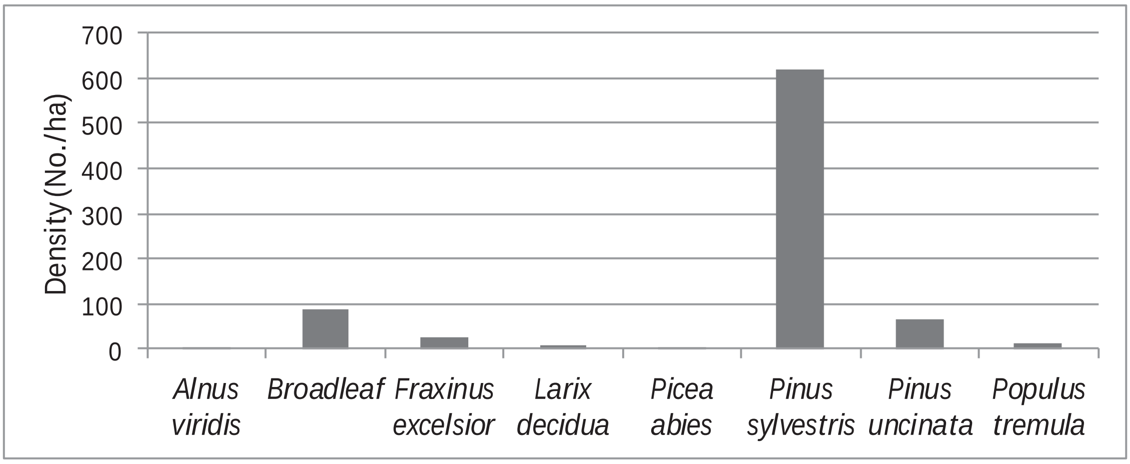


Figure 6: Density of tree species in sampled plot

Among the eight tree species, *Pinus sylvestris* has the highest density of around 617 trees/ ha whereas *Alnus viridis* and *Picea abies* less than 5 trees/ ha. Descriptive analysis is given in appendix 8.

## 4.2. Tree diversity:

About 16% of the plot contains only *Pinus sylvestris* trees and 74 % of the sampled plot having canopy cover of 50 to 75%. Similarly 13% of the plots have canopy coverage of less than 50% and more than 75% respectively. Within the plots, the Shannon diversity index ranges from 0 to 1.3. The average Shannon diversity index is 0.9 and species richness and evenness is 0.97 and 0.43 respectively.

### 4.3. Descriptive statisics of *Pinus sylvestris* forest

Out of 1276 sampled trees 956 are *Pinus sylvestris*. Histograms of elevation, DBH and height are shown in appendix 9. DBH of *Pinus sylvestris* ranges from 3 to 59cm with an average DBH of 18cm and the basal area coverage is 20.83 $m^2$/ ha. Similarly, maximum average height of the sampled tree was found to be 23 m with average height of 13m. In study area *Pinus sylvestris* trees was found within the range of 1420 to 1600m. More than 70% of sampled *Pinus sylvestris* tree DBH class belongs to pole size (DBH=10 to 30cm) and 17% and 12% of tree belongs to sapling (DBh <10cm) and sawlog category (>30cm).General descriptive statistics of *Pinus sylvestris* tree parameters are given in appendix 9.

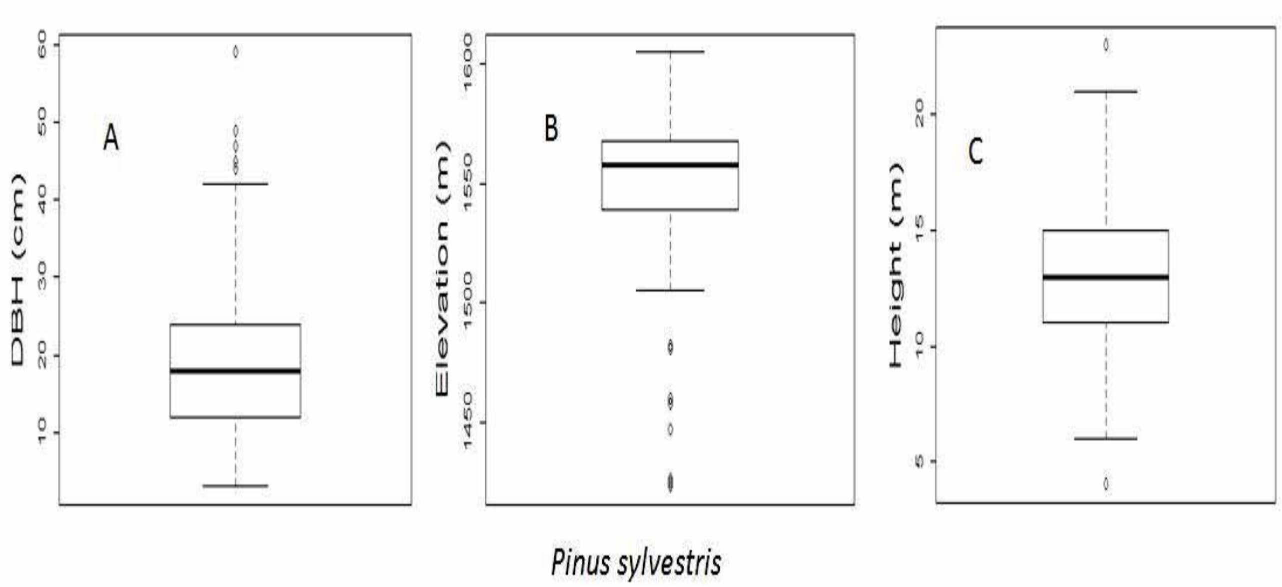


Figure 8: Pinus sylvestris tree parameters (A) DBH, (B) Elevation, (C) Height

#### 4.3.1. Relationship of DBH and height

Scatter plot shows that there is a weak relationship between the height and DBH of *Pinus sylvestris* trees. There is a minimum or no increase in DBH as height increases. The regression equation and obtained $R^2$ value is shown in the figure 10.

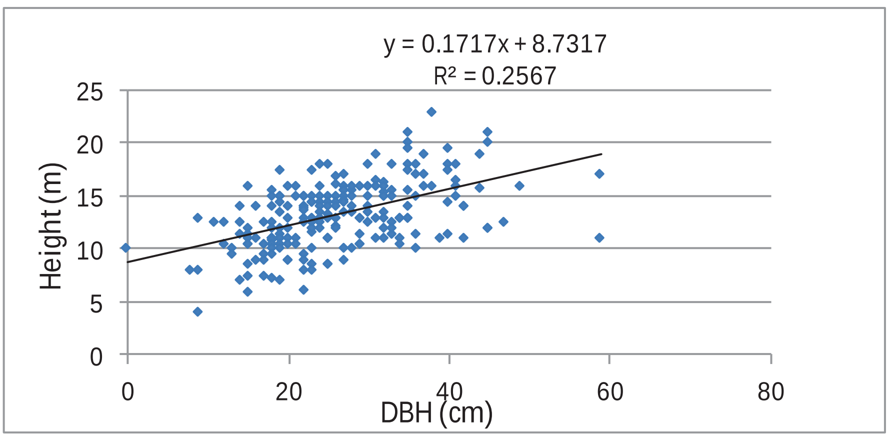


Figure 9: Scatter plot showing relationship of DBH and height of *Pinus sylvestris*

### 4.4. Descriptive anlysis of presence of *Viscum album* in *Pinus sylvestris*

Out of 31 sampled plots, 17 plots have presence of *Pinus sylvestris*. Descriptive analysis of density, relative density, frequency, relative frequency, abundance, basal area and relative basal area was presented in appendix 12. Within the *Viscum album* affected *Pinus sylvestris* trees, less than one third of *Pinus sylvestris* have high density of *Viscum album* which is shown in figure 11.

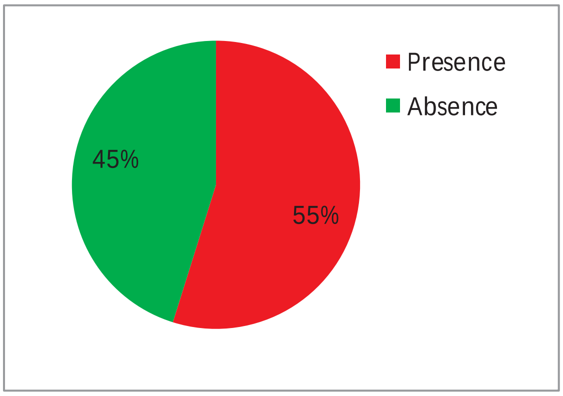


Figure 11: Incidence of *Viscum album in Pinus sylvestris* trees

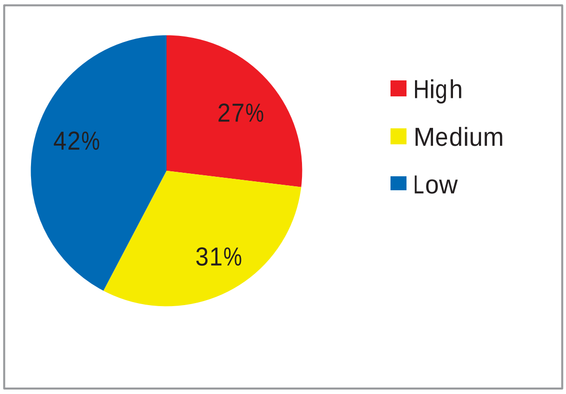


Figure 10: Relative frequency of *Pinus sylvestris* having different density level of *Viscum album*

The overall density of *Pinus sylvestris* tree is 618 trees/ha whereas the density of *Pinus sylvestris* having *Viscum album* is 40 trees/ha. Most of the affected *Pinus sylvestris* trees have medium level of *Viscum album* which accounts around 16 trees/ha and almost equal number of trees has presence of high and low (13 and 12 trees/ha respectively) density of *Viscum album*. Around 3.5 ha of basal area are covered by *Pinus sylvestris* trees having *Viscum album*.

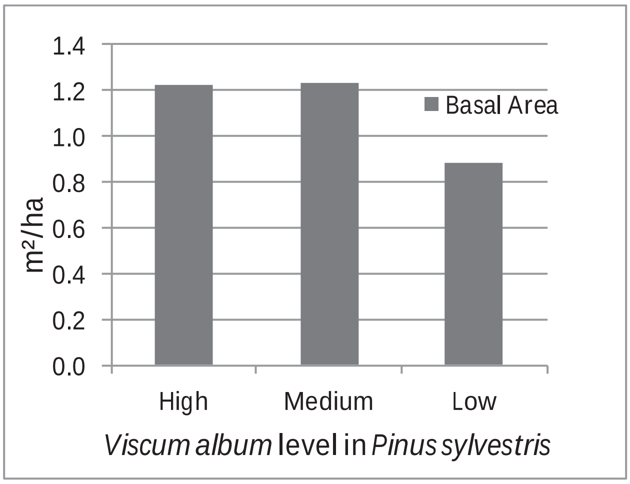


Figure 13: Basal area and of *Pinus sylvestris* having different level of *Viscum album*

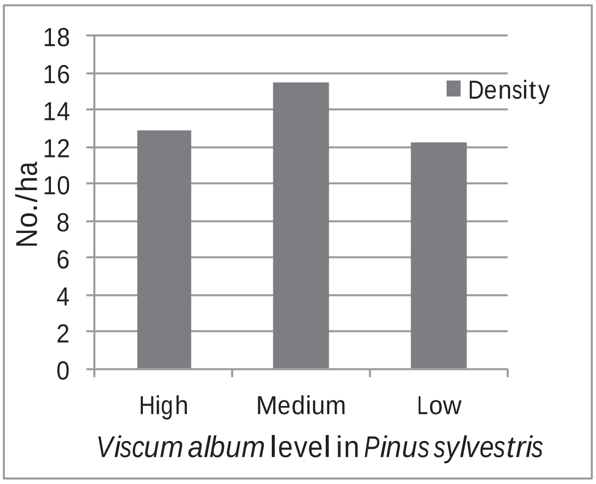


Figure 12: Density of *Pinus sylvestris* having different level of *Viscum album*

The relative frequency of *Pinus sylvestris* trees with low density *Viscum album* is almost half of the total affected trees whereas nearly equal distribution of high and medium density level of *Viscum album* in *Pinus sylvestris* is found in the study area. However, the relative abundance of low density *Viscum album* in *Pinus sylvestris* trees is less than other two classes.

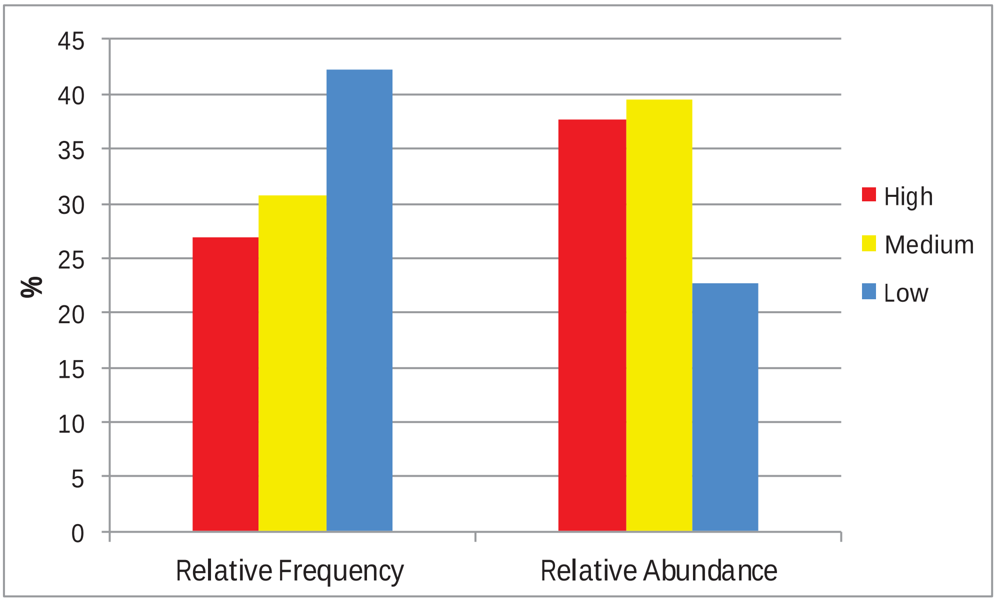


Figure 14: Relative frequency and relative abundance of *Pinus sylvestris* having different density class of *Viscum album*

## 4.5. Relationship of *Viscum album* in *Pinus sylvestris* with elevation and DBH

Presence and absence of *Viscum album* in *Pinus sylvestris* is equally distributed (around 6%) in lower elevation ranges from 1420 to 1500m. High percentage (36%) of presence of *Viscum album* was found between the elevation ranges of 1500 to 1550m. However, in higher elevation the presence of *Viscum album* is lower in *Pinus sylvestris* trees.

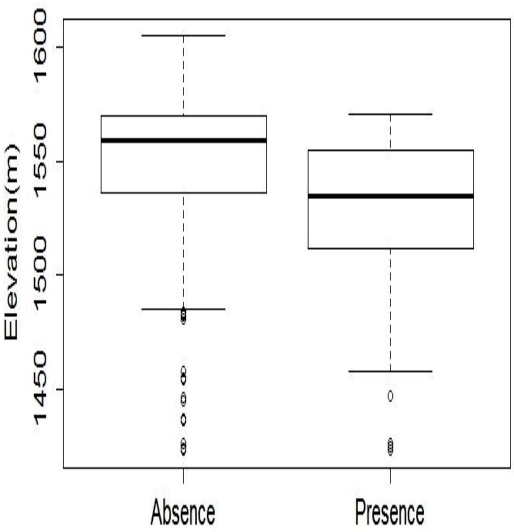


Figure 15: Incidence of *Viscum album* and elevation (m) (plots)

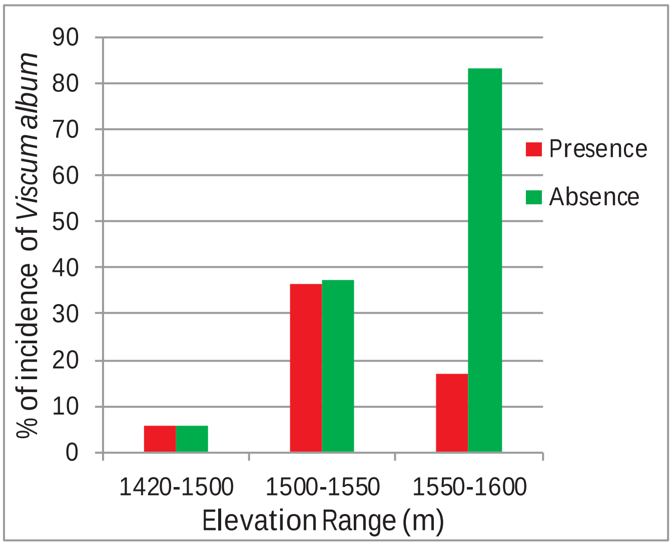


Figure 16: Incidence of *Viscum album* in different elevation ranges (plots)

The presence of *Viscum album* is low in *Pinus sylvestris* having low DBH and big DBH have high presence of *Viscum album*. In sampled trees, 10% of *Pinus sylvestris* trees have presence of *Viscum album* having DBH more than 30cm and only 0.3% of *Pinus sylvestris* have occurrence of *Viscum album* having DBH less than 15cm.

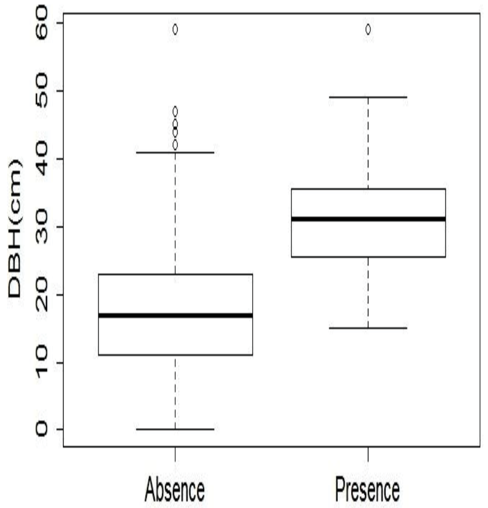


Figure 18: Boxplot of *Pinus sylvestris* DBH of presence/absence of *Viscum album* (plots)

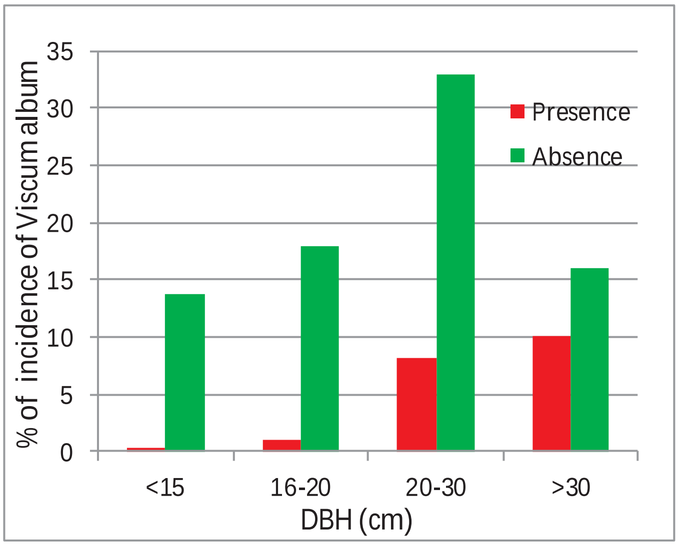


Figure 17: Presence of *Viscum album* in *Pinus sylvestris* per DBH class (plots)

*Pinus sylvestris* having DBH less than 15cm has only low density level of *Viscum album* where as DBH greater than 30cm have all three density (high, medium,low) level of *Viscum album* and contributing 18% of presence of high density *Viscum album*.

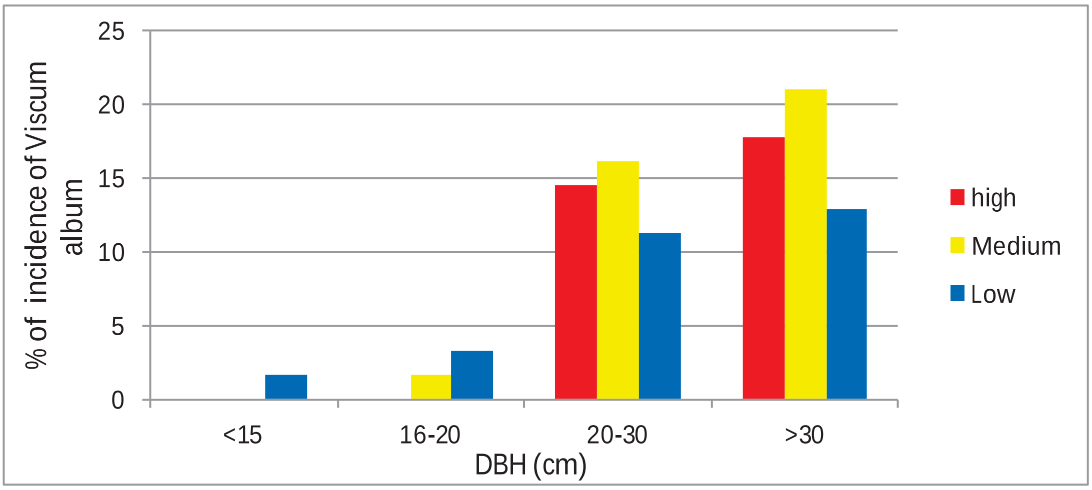


Figure 19: Percentage of occurrence of different density level of *Viscum album* on different DBH classes of *Pinus sylvestris*

A negative correlation between the *Viscum album* incidences on *Pinus sylvestris* and elevation ($r=-0.52$; $p<0.001$). However there was a positive significant correlation between the *Viscum album* incidences on *Pinus sylvestris* and DBH ($r=0.52$; $p<0.001$). Both T-test and ANOVA test ay 95% confidence level showed (table 4 and 5) the significant relationship between presence of *Viscum album* in *Pinus sylvestris* with elevation and DBH.

Table 4. T-test for determining relationship of presence of *Viscum album* with elevation and DBH

| Variables | d.f. | t-stat | t-Critical | p-value | Pearson correlation (r) | Conf. interval |
|---|---|---|---|---|---|---|
| Elevation | 54 | 7.25 | 1.6736 | 1.60E-09 | -0.5135 | 95% |
| DBH | 54 | 7.3663 | 1.6736 | 1.05E-09 | 0.5273 | 95% |

Table 5. ANOVA for determining relationship of presence of *Viscum album* with elevation and DBH

| Variables | d.f. | F-Stat | F Critical | p-value | Conf. interval |
|---|---|---|---|---|---|
| Elevation | 317 | 20.39 | 3.87 | 0.00 | 95% |
| DBH | 315 | 41.59 | 3.87 | 0.00 | 95% |

## 4.6. Multiple regression

The model developed through multiple regression method was tested using t-test and F-test. Though, $R^2$ is value is only 0.4453 the model is statistically significant at 95% confidence level. A summary of the test is given in table (6 & 7) and the equation of the model is as follows:

$$Y=8.4865 + (-0.00567) *(\text{Elevation}) + 0.0248*\text{DBH}$$

Table 6. Summary of multiple regression for prediction of *Viscum album* in *Pinus sylvestris trees*

| Variable | Estimate | Standard Error | t | Pr>\|t\| | Significances at alpha=0.5 |
|---|---|---|---|---|---|
| Intercept | 8.4865636 | 1.2523623 | 6.776 | 1.96E-10 | Very significant |
| Elevation | -0.00567 | 0.0007945 | -7.136 | 2.69E-11 | Very significant |
| DBH | 0.0248498 | 0.003341 | 7.438 | 4.92E-12 | Very significant |

Table 7. Summary of goodness of fit

| Test Statistics/ Parameters | Value |
|---|---|
| $R^2$ | 0.4453 |
| Adjusted $R^2$ | 0.4387 |
| F-statistic | 67.83 on 2 and 169 DF |
| p-value | < 2.2e-16 |

## 4.7. Logistic regression

Stepwise logistic regression was performed to estimate the best fit model. The model with both explanatory variables Elevation and DBH result in the lower AIC value (130) and the most significant model was chosen. The Nagaelkerke R-square value for this model is 0.58 and the equation is as follows:

$$Y=1(1+\exp(-1*(63.5+0.18*\text{DBH}-0.17*\text{Elevation})))$$

Table 8. AIC value of models

| Model No. | Explanatory Variables | AIC |
|---|---|---|
| 1 | Elevation, DBH | 130.05 |
| 2 | Elevation | 168 |
| 3 | DBH | 169.19 |

Both predictors are highly significant. Coefficients and significances of predictors of the best logistic regression model are shown in table 9.

Table 9. Coefficients and significances of predictors

| Predictors | Estimate | Std. Error | z value | Pr(>\|z\|) | Significances at alpha=0.5 |
|---|---|---|---|---|---|
| Intercept | 63.5 | 13.67 | 4.65 | 3.35e-06 | Very significant |
| DBH | 0.18 | 0.033 | 5.36 | 8.09e-08 | Very significant |
| Elevation | -0.045 | 0.009 | -4.96 | 7.12e-07 | Very significant |

## 4.8. Image processing

WV-2 image and Ortho photo were considerably matched after the geometric correction. The WV-2 image was shifted 12m from its original location. For instance, a house was matched in both images (Ortho and WV-2) which are shown in figure 20.

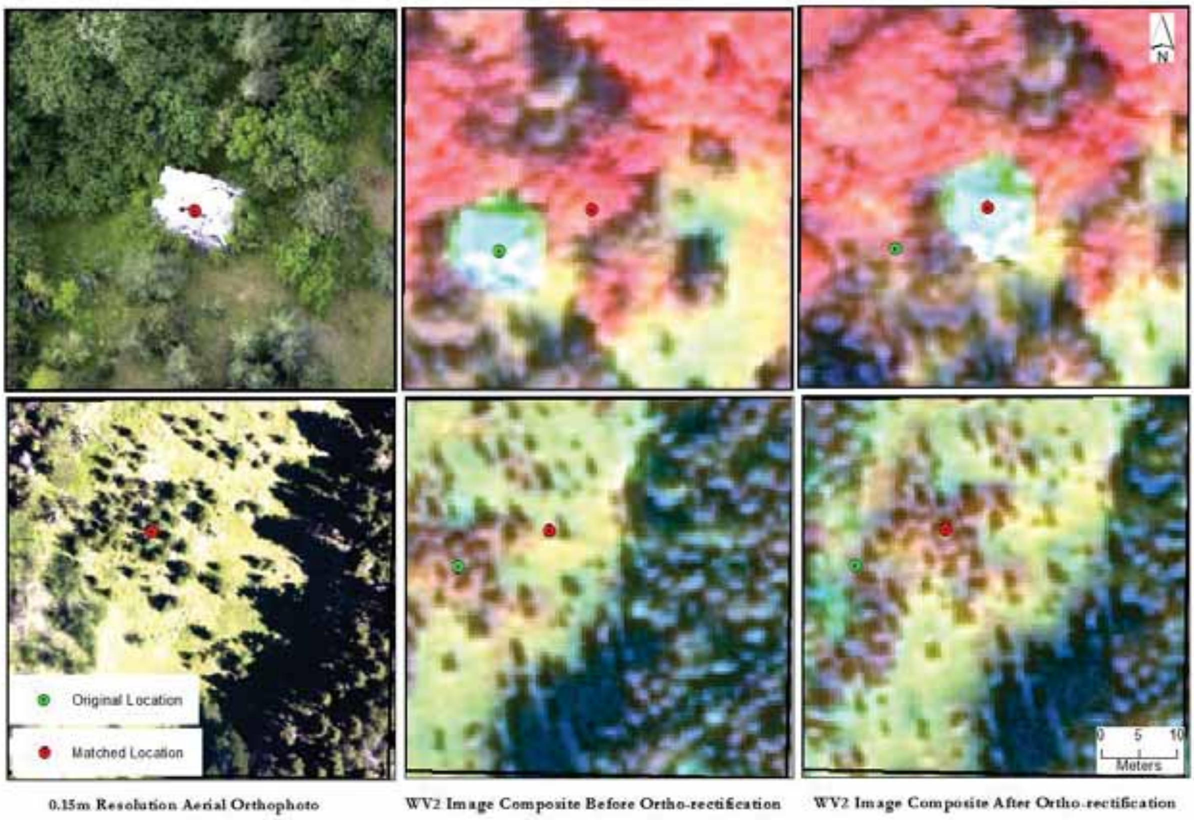


Figure 20: Image location showing 'before' and 'after' geometric correction

## 4.9. Image classification

High overall classification accuracy (96%) was achieved for the mapping of distribution of *Pinus sylvestris*. Among three classes namely (i) *Pinus sylvestris*, (ii) broadleaf and (iii) others, the user accuracy is higher for *Pinus sylvestris* (97%) and least for the class others. Similarly, the overall Kappa value of 0.84 was obtained for tree species classification.

Table 10. Species classification accuracy assessment

| | Species | Reference | | | | Error Commission % | User Accuracy % |
|---|---|---|---|---|---|---|---|
| | | *Pinus sylvestris* | Broadleaf | Others | Total | | |
| Classified | *Pinus sylvestris* | 220 | 4 | 2 | 226 | 2.65 | 97.35 |
| | Broadleaf | 0 | 16 | 1 | 17 | 5.88 | 94.12 |
| | Others | 3 | 1 | 17 | 21 | 19.05 | 80.95 |
| | Total | 223 | 21 | 20 | 264 | | |
| | Error Omission | 1.34 | 23.81 | 15 | | Overall Accuracy (%) | 95.83 |
| | Producer Accuracy % | 98.65 | 76.19 | 85 | | | |

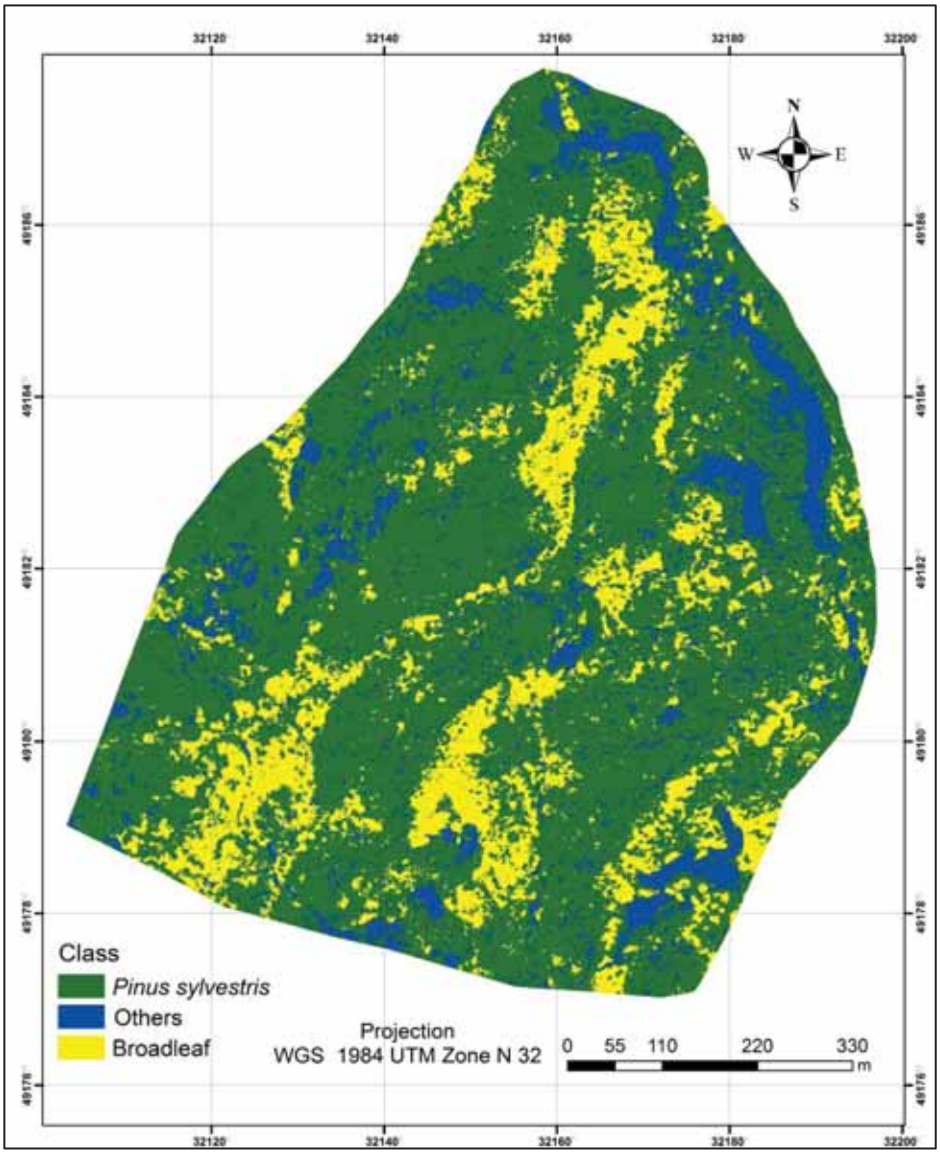


Figure 21: Distribution map of *Pinus sylvestris* in Bois noir, Barcelonnette France (WV-2 image)

## 4.10. Spectral analysis of *Pinus sylvestris* in the presence and absence of *Viscum album*

Spectral distinctness of *Pinus sylvestris* in the presence and absence of *Viscum album* is clearly observed in all eight bands of the WV-2 image. All band showed a similar trend of spectral curve for both presence and absence of *Viscum album* in *Pinus sylvestris*. Furthermore, *Pinus sylvestris* in the presence of *V. album* has a low spectral reflectance in all bands. However, NIR1, NIR2 and red edge have the highest spectral distinctness compared to other bands. In the red edge, there is a sharp rise in the reflectance curve in both presence and absence of *Viscum album*. However the presence of *Viscum album* shows a short sharp rise compared to *Pinus sylvestris* in the absence of *Viscum album*. Spectral reflectance of *Pinus* with and without *Viscum album* is shown below:

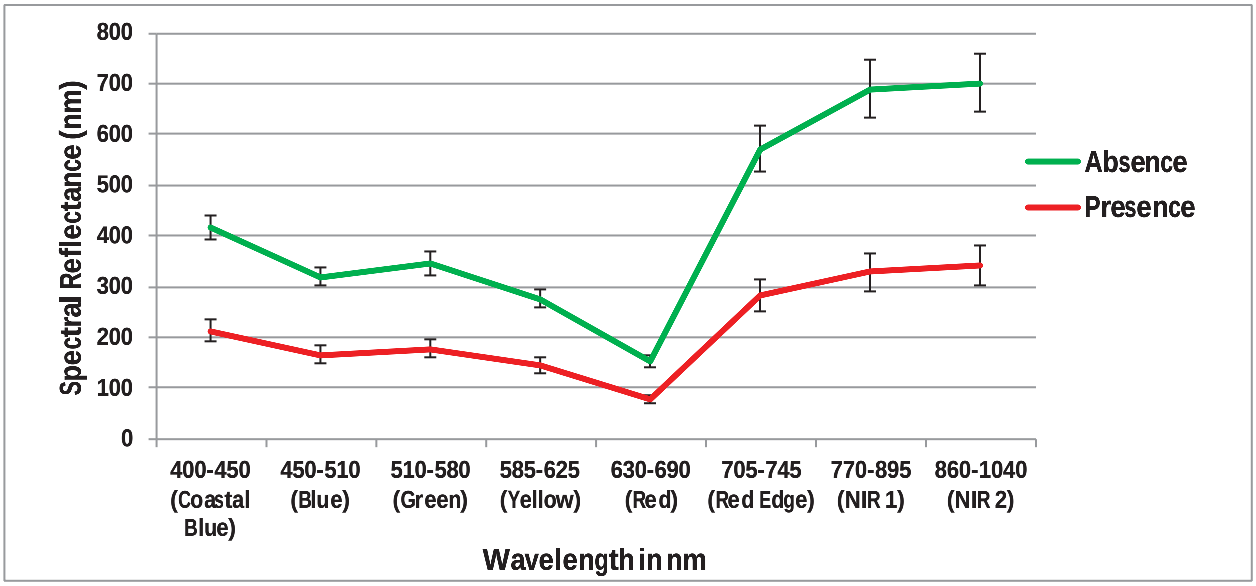


Figure 22: Spectral reflectance of *Pinus sylvestris* in the presence and absence of *Viscum album*

## 4.11. Analysis of vegetation indices (NDVIs)

The mean NDVI pixel value of presence and absence of *Viscum album* was calculated which is given in table 4-8. In all three calculated indices, the NDVI value is lower in presence of *Viscum album* in *Pinus sylvestris*. However, NDVI value (presence=0.61, absence =0.70) obtained from band combination of 8 and 5 (NIR2 & red band) is able to detect the presence of *Viscum album* better compared to other two indices.

Table 11. Reflectance value of three vegetation indices

| NDVI | *Viscum album* | |
|---|---|---|
| | Presence | Absence |
| 76 | 0.090 | 0.097 |
| 85 | 0.619 | 0.704 |
| 86 | 0.100 | 0.155 |

NDVI 85 was significant at (alpha=0.05, p-value<0.00) for discriminating the presence and absence of *Viscum album* in *Pinus sylvestris*. However, NDVI 76 was not significant at alpha of 0.05. Furthermore, a Kruskal-Wallis test showed NDVI 85 was significantly different (p<0.0167) from NDVI 76 and NDVI 85. NDVI 85 had highest discrimination and was significantly different from other two vegetation indices.

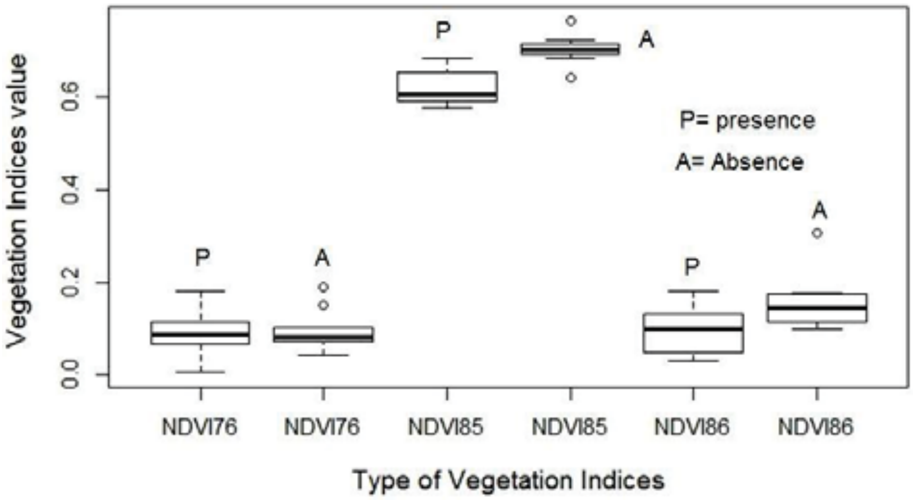


Figure 23: Boxplot of reflectance value of three different vegetation indices for presence and absence of *Viscum album* in *Pinus sylvestris*

### 4.12. Classification of presence and absence of *Viscum album* in *Pinus sylvestris* in the WV-2 image

The WV-2 image was successfully classified to detect the presence and absence of *Viscum album* in *Pinus sylvestris* by applying pixel based MLC. The overall classification accuracy of 86% with overall kappa value of 0.52 was achieved for detection of presence of *Viscum album* in *Pinus sylvestris* forest. The user accuracy of 72% was achieved for presence of *Viscum album* and 88% for absence of *Viscum album*. The kappa (K^) statistics for presence and absence of *Viscum album* are given in table 12 and 13.

Furthermore, the true skill statistic value of 0.6 was obtained for the detection of *V. album*. The error of commission and omission for the presence of *Viscum album* is higher (28% and 48% respectively) than the absence of *Viscum album*. Even though the overall accuracy is higher, the false presence rate is also higher 0.48 compared to false absence rate. Similarly, sensitivity and specificity of the classified image was obtained 0.72 and 0.88 with true skill statistics value of 0.6.

Table 12. Accuracy assessment for the WV-2 image for presence and absence of *Viscum album* in *Pinus sylvestris*

| | Status | Reference | | | Error Commission % | User Accuracy % |
|---|---|---|---|---|---|---|
| | | Presence | Absence | Total | | |
| Classified | Presence | 13 | 5 | 18 | 27.78 | 72..2 |
| | Absence | 12 | 93 | 105 | 11.43 | 88.5 |
| | Total | 25 | 98 | 123 | | |
| | Error Omission | 48 | 5.1 | | Overall Classification Accuracy (%) | 86.2 |
| | Producer Accuracy % | 52 | 94 | | | |

Table 13. Kappa value for presence and absence of *Viscum album* for classified WV-2 image

| Status | Kappa (K^) |
|---|---|
| Presence of *Viscum album* | 0.6514 |
| Absence of *Viscum album* | 0.4377 |

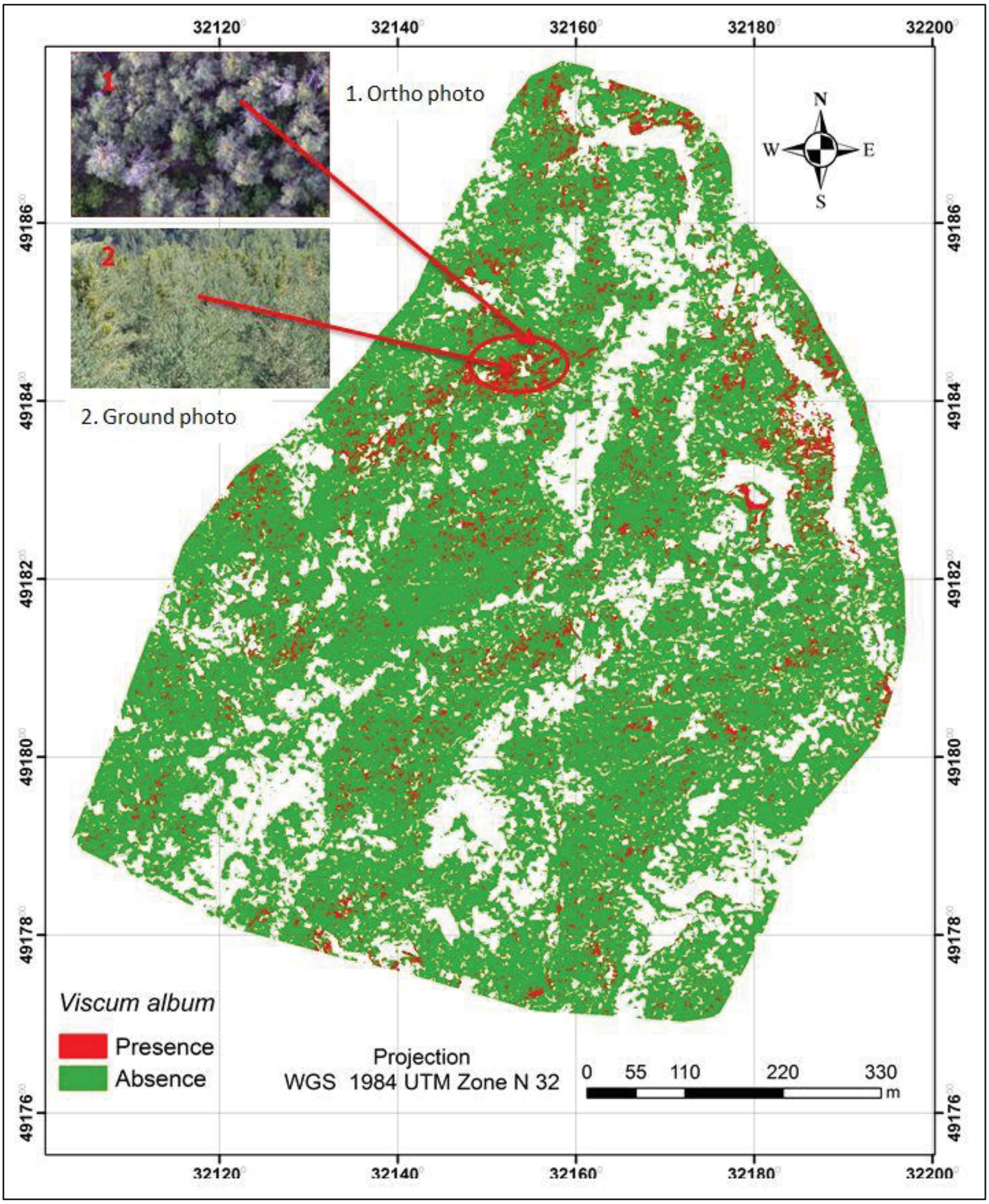


Figure 24: Distribution map (WV-2) of presence of *Viscum album* in *Pinus sylvestris* forest

### 4.13. Classification of presence and absence of *Viscum album in Pinus sylvestris* on airborne multispectral Ortho image

The overall classification accuracy of 77.7% with overall kappa value of 0.3662 was obtained for detection of presence and absence of *Viscum album* in *Pinus sylvestris* trees. The kappa (K^) statistics for individual species is given in table 4-11 and 4-12. Similarly, sensitivity and specificity of the classified image was obtained 0.71 and 0.78 with true skill statistics value of 0.5.

Table 14. Accuracy assessment for Ortho image for presence and absence of *Viscum album* in *Pinus sylvestris*

| | Status | Reference | | | Error Commission % | User Accuracy % |
|---|---|---|---|---|---|---|
| | | Presence | Absence | Total | | |
| Classified | Presence | 15 | 6 | 21 | 28.6 | 71.43 |
| | Absence | 25 | 93 | 118 | 21.18 | 78.81 |
| | Total | 40 | 99 | 139 | | |
| | Error Omission | 62.5 | 6.06 | | Overall Accuracy (%) | 77.7 |
| | Producer Accuracy % | 37.5 | 93.94 | | | |

Table 15. Kappa value for presence and absence of *Viscum album* for classified Ortho image

| Status | Kappa (K^) |
|---|---|
| Presence of *Viscum album* | 0.5988 |
| Absence of *Viscum album* | 0.2638 |

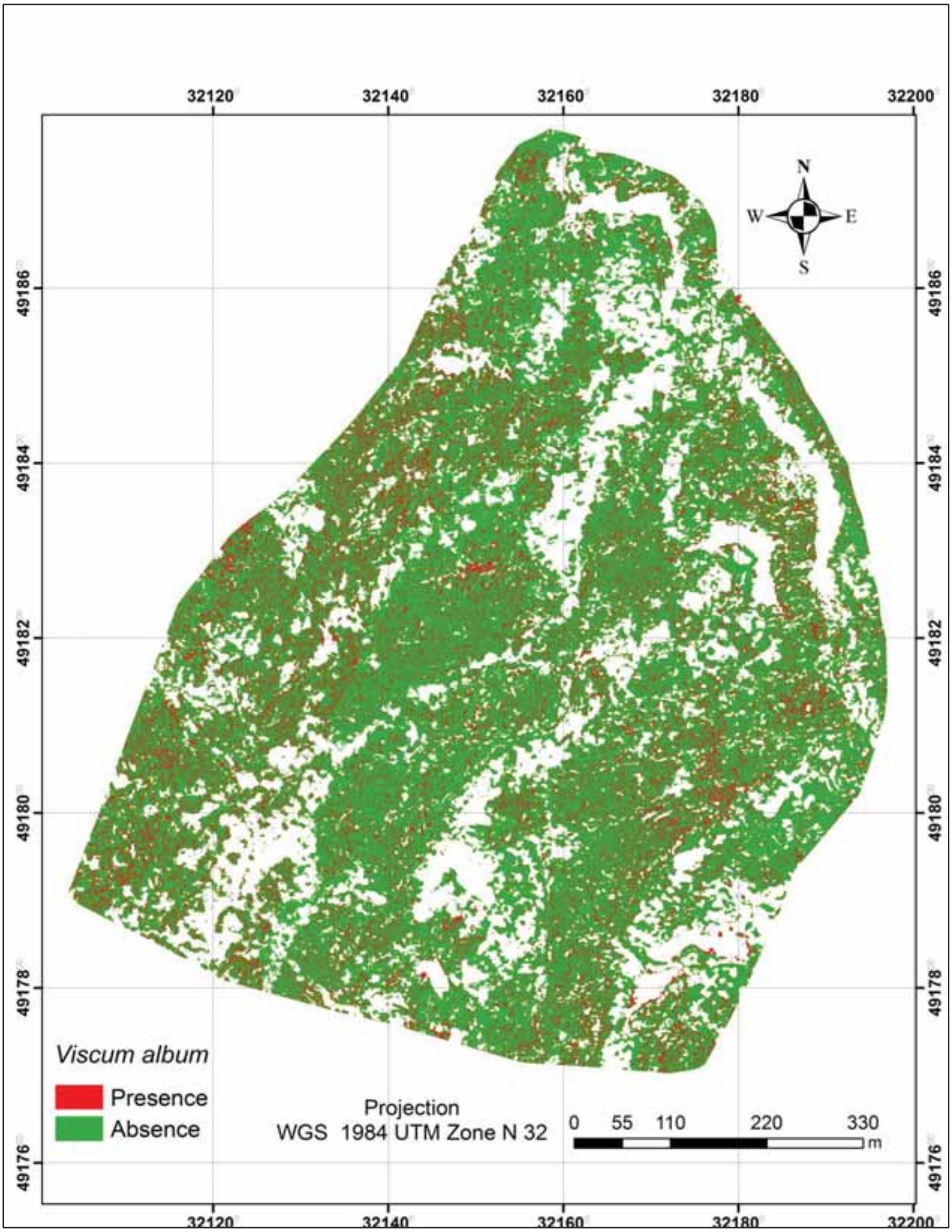


Figure 25: Distribution map (Ortho image) of presence of *Viscum album* in *Pinus sylvestris* forest

# 5. DISCUSSION

## 5.1. *Pinus sylvestris* plantation forest

Low tree diversity combined with high tree density is the characteristics of plantation forest (Hartley, 2002). The *Pinus sylvestris* tree density (823/ha) found in the study area is six times higher than that of (132/ha) the natural pine forest (Summers et al., 1999). Pole size *Pinus sylvestris* dominated in the Bois noir whereas the stem size is more diverse in natural pine forest (Kint, 2005; Summers et al., 1999). Furthermore, Watt and Kirschbaum (2011) found that the tree DBH and height of even-aged plantations coniferous have a linear relationship (0.73 $R^2$). However, in our area *Pinus sylvestris* DBH and height show a weak relationship (0.25 $R^2$). Similarly, the obtained Shannon index (0.9), species richness (0.97) and evenness (0.43) show low tree diversity compared to results obtained by Lilja and Kuuluvainen (2005) for near natural *Pinus sylvestris forest* (Shannon index of 1.88). Similarly, Pourababaei et al. (2012) found the species richness of 1.71 for coniferous plantation. According to Zhang et al. (2012) higher species richness and evenness can improve the productivity and diversity of the forest. In plantation forest, understory vegetation were reduced by the dense stand and adversely affect the native species (Gómez-Aparicio et al., 2009). However, the diversity and species richness increases in plantation forest in less than a century (Lust et al., 1998). Although the plantation forest is more than 100 years old, the species diversity is low and the tree DBH is not significantly correlated with height. The growth rate of the tree is significantly lower in Bois noir (Saez et al.). Similarly, the reason for low diversity could be the lack of relict montane conifer forest. Furthermore, there is no thinning and harvesting of trees and the reason could be the inaccessibility of the sites for the timber harvest. Thinning of the sites can upgrade the study area diversity and Abella (2010) emphasized that thinned plot can increase diversity richness up to three times more than un-thinned plots.

## 5.2. Relationship of *Viscum album* in *Pinus sylvestris* with elevation and DBH

Even in the small range of elevation (1420-1650m) there is a significant negative ($r=-0.5135$; $p<0.00$) correlation between the *Viscum album* and elevation. The incidence of high density *Viscum album* in *Pinus sylvestris* is high at lower elevation and low in higher elevation. A significant negative relationship ($r=-0.7$; $p<0.01$) of incidence of *Viscum album* in conifers (silver fir) with elevation (up to 600 m-very high incidence) was observed in Eastern Carpathians (Barbu 2012). Dobbertin et al. (2005a) also found that around 37% of his sampled *Pinus sylvestris* trees were affected by *Viscum album* up to an elevation range of 1550 m and absent above this range. However, we found a positive correlation and significant relationship ($r=0.52$; $p<0.00$) between the DBH and incidence of *Viscum album* in *Pinus sylvestris*. The higher the DBH the more susceptible to incidence of *Viscum album* and other diseases. Barbu (2010) and Noetzli et al. (2003) also indicate that *Pinus sylvestris* trees more than 50 years old are more susceptible to incidence of *Viscum album*. Similarly, the mistletoe incidence on silver fir showed that is higher in trees older than 120 years (Barbu, 2010).

Elevation and DBH are successful explanatory predictors in the linear multiple and logistic models. The relation of the models are weak although significant ($p<0.00$) at 95% confidence interval. However, species distributions and its responses depend on several environmental variables (Austin, 2007). The models may be improved by testing other variables such as a broader elevation range, tree density, tree height, slope, aspect, temperature and rainfall. Furthermore, other models like Maxent, (van Gils et al., 2012), neural network and Bayesian models (Guisan & Zimmermann, 2000; Joshi et al., 2006) can be compared with multiple linear and logistic models.

## 5.3. Analysis of spectral reflectance and vegetation indices

In the presence of *Viscum album*, *Pinus sylvestris* has a low reflectance in all spectral bands (Visible and NIR bands) whereas high reflectance is shown by *Pinus sylvestris* in absence of *Viscum album* in the NIR band. Photosynthetically active vegetation has a higher reflectance in the NIR band than stressed and photosynthetically inactive vegetation (Beeri et al., 2007; Carter & Knapp, 2001) thus, the *Pinus sylvestris* in presence of *Viscum album* may be under stress and photosynthetically less active compared to *Pinus sylvestris* in the absence of *Viscum album*.

A research by Eitel et al. (2011) has shown that the red edge band has the capability to detect the stress in plants due to changes in $Chl_{ab}$; a significant result in early stress detection in a conifer forest was found. According to Carter and Knapp (2001), transmittance, reflectance and absorptance of the stressed and healthy vegetation can be better distinguished in NIR. Similarly, in this research the *Pinus sylvestris* with *Viscum album* resulted in a decrease in absorption in the red band and a shift to the red edge and a larger difference in band NIR1 and NIR2.

NDVI 85 has the potential to differentiate the presence and absence of *Viscum album* in *Pinus sylvestris.* Ismail et al. (2008) and Ismail et al. (2006) also revealed that NDVI shows the better performance compared to other vegetation indices in detecting the *Pinus patula* tree infestation by *Sirex noctilio*. Similarly, the previous research done by Bhattarai et al. (2011) has also obtained a significant result (p-value =-0.09) to discriminate *Sirex* woodwasp infested *Pinus sylvestris* in WV-2 by using NDVI 85. NDVI 85 value of *Pinus sylvestris* trees was lower in the presence of *Viscum album* which indicates a reduced in the total green biomass (chlorophyll) or leaf area index (LAI) of the *Pinus* trees. According to Adams et al. (1999) there is less absorption by chlorophyll and less reflectance in the near infrared region in the stressed vegetation.

## 5.4. Image classification and accuracy assessment

### 5.4.1. *Pinus sylvestris* distribution map

Our overall classification accuracy (96%) and Kappa value (0.84) of our research showed the high standard (acceptable level >85%) of classification accuracy for optical data (Ismail & Jusoff, 2008). Our classification accuracy is high compared with the overall accuracy of 86% and overall kappa value of 0.77 for classifying three classes (coniferous, broadleaf and non-forest) by applying a support vector machine classifier in multispectral imagery (Dalponte et al., 2012). Similarly, Dalponte et al. (2012) has been able to increase the overall accuracy level to 91.5% and overall kappa (0.86) for the same three classes (coniferous, broadleaf and non-forest) by using spectral bands and LiDAR extracted tree height features. Likewise, Holmgren et al. (2008) has achieved an overall classification accuracy of 91% for Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) and deciduous trees using multispectral aerial imagery. The reasons behind the high classification accuracy in our research compared to other researches could be the high number of ground reference data (>250) (Ismail & Jusoff, 2008), low number of classes (Immitzer et al., 2012a), low diversity forest with distinct even-aged trees (conifers and broadleaf) (Digital Globe, 2009) and additional spectral bands (red edge, NIR2 ) in WV-2 image. Tree species classification by Immitzer et al. (2012a) using WV-2 imagery has improved the classification accuracy from 84 to 95% when he reduce the classes from 10 to 4 (namely; *Picea abies, Pinus sylvestris, Fagus sylvatica, Querus robur*). This confirmed that the classification accuracy increases as the number of classes is lower. Similarly, Ismail and Jusoff (2008) has improved the classification accuracy from 83 to 89% when he increases the reference data. Furthermore, red edge, NIR1 and NIR2 of WV-2 image plays a key role in class separability (Immitzer et al., 2012a). Additional spectral band of WV-2 identified coniferous and broadleaf trees with 99% accuracy (Immitzer et al., 2012b). Similarly, Pu and Landry (2012) improved the overall classification accuracy of mapping urban tree species on WV-2 compared to IKONOS due to additional bands especially yellow, red-edge and NIR2 of WV-2.

#### 5.4.2. Detection of *Viscum album* in *Pinus sylvestris* in WorldView-2 and the Ortho image

Overall classification accuracy for the WV-2 (86%) and Ortho image (77%) for detection of *Viscum album* in *Pinus sylvestris* is somewhat lower than the Meddens et al. (2011) findings. Meddens et al. (2011) applied MLC to detect the mountain pine beetle attack using digital aerial imagery with spatial resolutions of 30cm, 1.2m, 2.4m and 4.2m and obtained the highest overall accuracy (90%) and kappa (0.88) in 2.4m spatial resolution. Spruce et al. (2011) obtained the overall accuracy of 88% for detecting forest defoliation by gypsy moth using coarse resolution (250 m) MODIS NDVI time series. Kantola et al. (2010) has achieved a higher accuracy (88%) for classification of defoliated *Pinus sylvestris* trees caused by pine sawfly by combining high pulse density airborne laser scanning (ALS) data and aerial digital imagery. Similarly, Rencz and Nemeth (1985) also achieve a higher accuracy of more than 80% for detecting the *Dendrococtonus ponderosae* infestation in *Pinus* trees by using coarse resolution (30 m) Landsat MSS.

A comparison of the 2m resolution WV-2 and 0.15m resolution Ortho photo classification outputs shows that the WV-2 imagery of lower spatial but higher spectral resolution gave 9% higher classification accuracy. This is interesting to note as it indicates that high spatial resolution does not necessarily result in better *Viscum album* detection. Many researchers (Bhattarai et al., 2011; Meddens et al., 2011; Quackenbush et al., 2000; Rencz & Nemeth, 1985; Wulder et al., 2006) shows a finer similar results of weak detection on finer spatial resolution imagery for detection of parasites. Spectral reflectance values convey information on biophysical, biochemical and physiological characteristics of vegetation features and therefore can be used to distinguish vegetation along the spectrum (citation). Since MLCs rely on the 'spectral signature' to distinguish between species, the higher the spectral resolution, the more vegetation biophysical, biochemical and physiological characteristics may be detected from spectral data. The WV-2 imageries have four extra spectral bands that support vegetation identification. These include the coastal band that supports vegetation identification based upon its chlorophyll and water penetration characteristics. The yellow band which enhances identification of "yellow-ness" characteristics of targets (Digital Globe, 2009)and the red edge band that aids in the analysis of vegetative condition (Mutanga & Skidmore, 2004). With these extra spectral bands, the spectral signatures of *Pinus* and *Viscum album* are clearer in the WV-2 than in the orthophoto hence explaining the higher classification accuracies. On the other hand, although *Viscum album* is easily visually distinguishable, in higher spatial resolution imagery, there were mixed pixels in the classification based on the orthophoto. Yu et al (2006) attribute the salt and pepper noise to sun view geometry or bi-directional reflectance effects (Immitzer et al., 2012a; Immitzer et al., 2012b). Many pixels represent a single object in fine resolution imagery. Conifer crowns have even more mixed pixel effects due to low sunlit portions of trees (Immitzer et al., 2012b).

However, WV-2 and Ortho image were able to detect *Viscum album* in *Pinus sylvestris* with >75% accuracy. Our result may reflect the impact of Viscum album on the canopy of *Pinus sylvestris* (host) and not the spectral reflectance of *Viscum album* itself. In the ground survey the condition of the host could receive more attention.

### 5.5. Sources of error in image classification for detection of *Viscum album* in optical imagery

Notwithstanding advancement in remote sensing and availability of high spatial and spectral resolution satellite imagery, there are still challenges and uncertainties in accurately detecting and mapping the *Viscum album* in the *Pinus sylvestris* forest. The major challenges and problem faced during this research are discussed below:

- Positional error

Some errors occurred while using Garmin GPS and iPAQ to navigate the sampling plot to identify tree locations on the ground. The accuracy of the GPS and iPAQ ranges from 3 to 10 meters. Errors were due to poor satellite visibility and weak signal reception by the GPS because of canopy obstructions and cloud cover. For the mapping and detection of *Viscum album* at tree level, a high precision spatial accuracy is required. This condition was not fully fulfilled during this survey. Our DGPS was unable to connect a local base station. To get a cm level accuracy a DGPS needs to install. It will take at least 3-4 hours to establish a base station. This is time consuming, expensive, and not suitable in the study area due to rugged terrain and dense forest. However, to minimize the spatial error, LiDAR based canopy height model and printed 15cm spatial resolution Ortho map were used in the field to identify every sampled tree. Advantage of this high spatial resolution Ortho map was to identify and cross check the sample locations periphery.

- Sampling error due to dense canopy cover

Field sampling data plays a vital role in our research. However, some crucial errors occurred while recording the presence and absence of *Viscum album* in *Pinus sylvestris* on the ground. Mostly *Viscum album* is in the tree crown of the *Pinus sylvestris* and hard to see from the ground due to the dense canopy cover. Some of the sampling trees were recorded as without *Viscum album* in the field, while observation from the elevated areas and the Ortho photo (15cm) often revealed the presence of *Viscum album*. To minimize this sampling error the suspicious samples were removed from the analysis. Bird's eye view is required to establish the presence of *Viscum album* in *Pinus sylvestris*. Furthermore, this research also indicates the advantages of aerial survey over ground survey for detection of *Viscum album* in *Pinus sylvestris*.

# 6. CONCLUSIONS AND RECOMMENDATIONS

## 6.1. Conclusions

The research demonstrates the potential of high resolution optical satellite imagery (WV-2) and aerial ortho imagery for detecting *Viscum album* in *Pinus sylvestris*. *Pinus sylvestris* was classified with a high accuracy (96%). We are able to detect and map the *Viscum album* in *Pinus sylvestris* of Bois noir, Barcelonnette for the first time. The following conclusions were drawn out from the research findings:

- Is *Pinus sylvestris* with and without *Viscum album* is spectrally distinct?
  From the analysis of spectral characteristics of *Pinus sylvestris* in WV-2 image, it was revealed that there is a distinct spectral reflectance of *Pinus sylvestris* in the presence and absence of *Viscum album*. The Red edge, NIR1 and NIR2 bands of WV-2 show better separability.

- Can vegetation indices (NDVI-with different band combination) derived from multispectral imagery (WV-2) differentiate the presence and absence of *Viscum album* in *Pinus sylvestris?*
  Among three vegetation indices, NDVI 85 shows the highest performance in distinguishing the *Viscum album* in *Pinus sylvestris*.

- Is there any significant relationship in incidence of *Viscum album* in *Pinus sylvestris* with elevation and DBH?
  There is a significant negative correlation ($r=-0.5135$; $p<0.00$) and significant positive correlation ($r=0.52$; $p<0.00$) with elevation and DBH respectively for the incidence of *Viscum album* in *Pinus sylvestris*. Furthermore, the linear and logistic regression model show weak predictions although significant ($p<0.00$) at 95% confidence interval by including both elevation and DBH.

- How accurately can the incidence of *Viscum album* in *Pinus sylvestris* forest be detected by the use of maximum likelihood classification (pixel based classification) on WV-2 satellite and airborne Ortho imagery?
  An overall classification accuracy of 86% and a kappa of 0.52 was achieved on WV-2 for the detection of *Viscum album*, whereas in the airborne ortho image an accuracy (77%) and kappa (0.36). The user accuracy for both images was around 72% for the detection of *Viscum album* in *Pinus sylvestris*.

  Finally, the research indicated that the *Viscum album* can be detected in *Pinus sylvestris* by using remotely sensed very high resolution optical imagery.

## 6.2. Recommendations

The issue of high incidence of *Viscum album* in the tree species is regarded as an alarming concern for the continuation of *Pinus sylvestris* forest. *Pinus sylvestris* one of the keystone tree species has been dramatically affected by the presence of *Viscum album* in the study area. *Pinus sylvestris* forests are threatened throughout the Alps. Zuber (2004b) cited that Dicrano Pinion, Erica-Pinion and Ononido-Pinion are the main *Pinus* species communities where *Viscum album* can grow.

My recommendations are as follows:

- There are no sign of thinning and management of forest over a long period of plantations which need to harvest and thinned. Thinning of the dense *Pinus sylvestris* can help to maintain the diversity of the forest. Thinning also enhance the understory vegetation as well (Boakye et al., 2012).

- Substitution of mono-culture plantation of *Pinus sylvestris* by poly-culture plantation of other tree species which is less susceptible to incidence of *Viscum album* such as *Pinus uncinata, Larix decidua.* Since these species are growing at the same habitat in the study area in absence of *Viscum album*.

- Positional error and correct observations in the ground need to be addressed.

- The predictive model was developed on the basis of elevation and DBH only. Additional explanatory variables such as slope, aspect, tree height, and climate can be used to develop models. Other models like Maxent, Neural Network and Bayesian models maybe tested as well.

- Dobbertin et al. (2005a) reflects the incidence of *Viscum album* due to climate change (global warming). Is really climate change affecting the impact of *Viscum album* on *Pinus sylvestris*? Climatic variables need to study for better understand the relationship of incidence of *Viscum album* on Pinus species. Further research on ecology of *Viscum album* and *Pinus sylvestris* is recommended to understand the phenomenon of incidence of Viscum *album* on *Pinus species.*

- Spraying biological herbicides in the affected trees may minimize the growth rate of *Viscum album*.

- Wind and birds are the major vectors for the dispersal of *Viscum album*. Considering these (wind and bird migration) factors might be useful for minimizing the growth of *Viscum album* in *Pinus* species.

- Spatial distribution of *Viscum album* on host species is still mysterious, for example *Pinus sylvestris* is highly affected by *Viscum album* in Bois noir whereas there is no single incidence of *Viscum album* in *Pinus* in the Netherlands. What cause the *Viscum album* to select its host in a selective geographical area? What are the environmental and ecological factors for the incidence of *Viscum album*? Further research can be done on these queries.

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# LIST OF APPENDICES:

Appendix 1. Taxonomy of *Pinus sylvestris* and *Viscum album* :

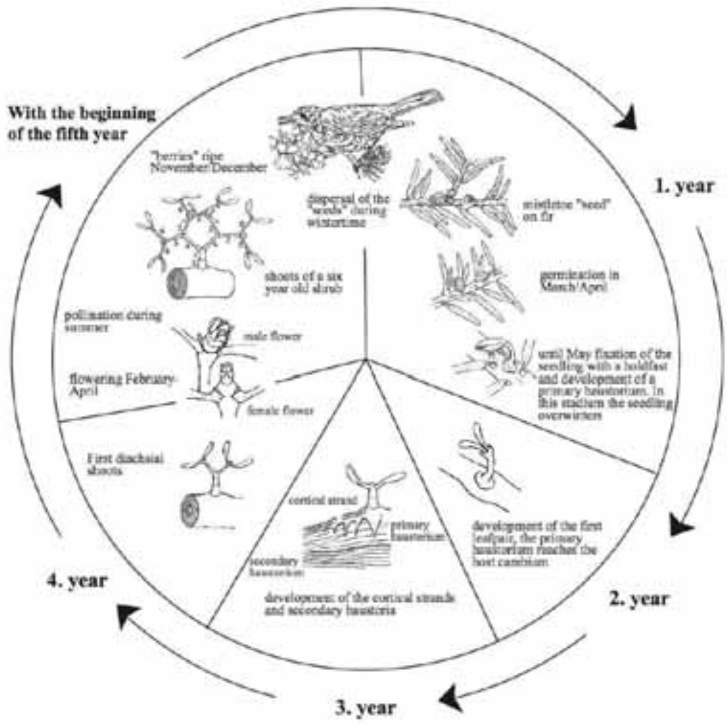
| Scientific Name | Common Name | Kingdom | Phylum | Class | Order | Family | Red List Category & Criteria |
|---|---|---|---|---|---|---|---|
| *Pinus sylvestris* | *Pinus sylvestris* | Plantae | Tracheophyta | Coniferopsida | Coniferales | Pinaceae | Lower Risk/Least Concern |

Source: (IUCN, 2012)

| Scientific Name | Common Name | Group | Family | Duration |
|---|---|---|---|---|
| *Viscum album* L. | European *mistletoe* | Dicot | Viscaceae | Perennial |

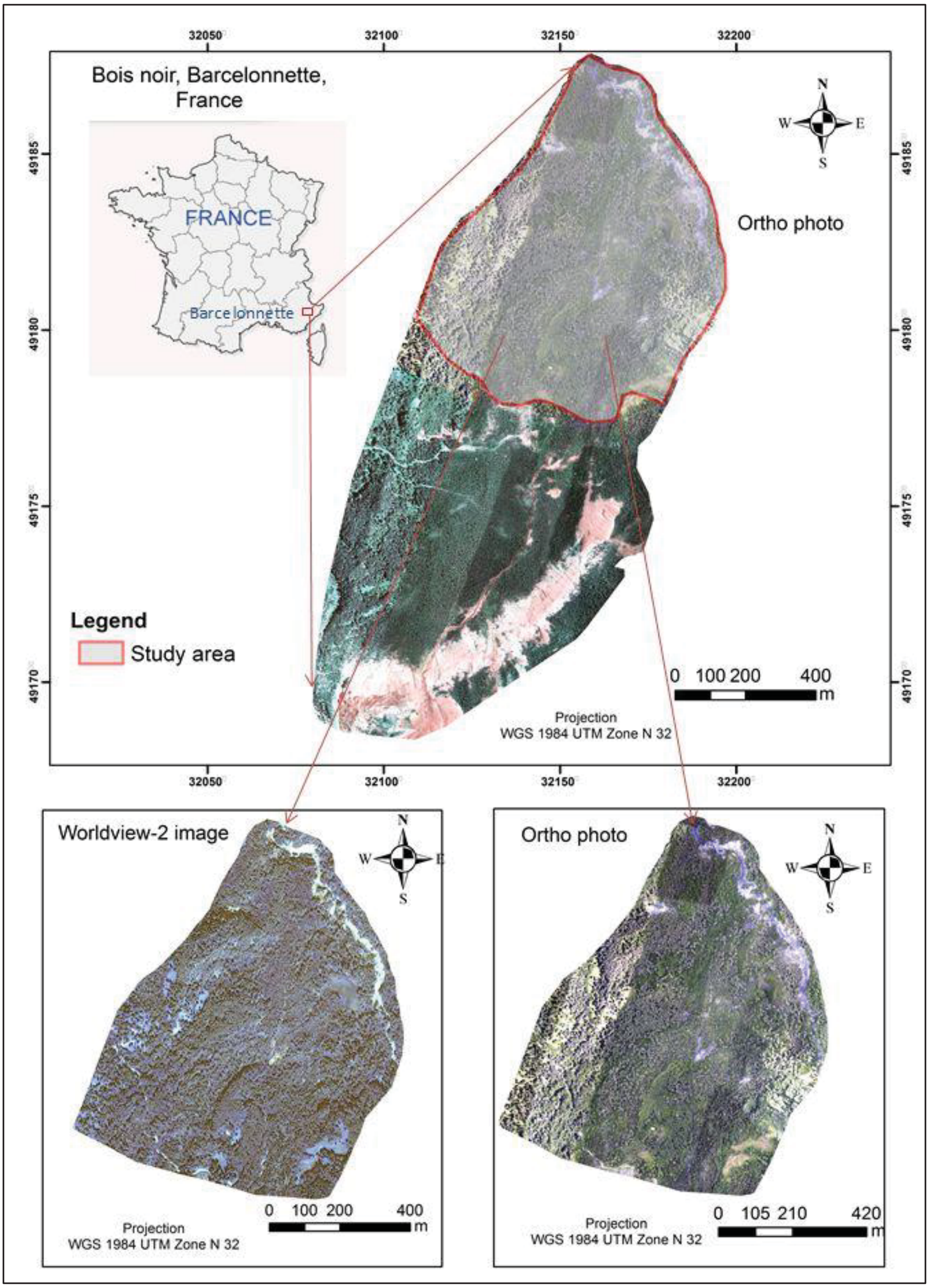
Source: (NRCS, 2012)

Appendix 2. Life cyde of *Viscum album*




Source: (Nierhaus-Wunderwald & Lawrenz 1997, Zuber 2004)

Appendix 3. Location map of the study area



Appendix 4. Features of WV-2 image

| **Sensor Name** | **WorldView-2** | |
|---|---|---|
| Launch Information | 13th September 2010 | |
| Acquisition Time | 10:40:30 | |
| Spectral Range (nm) | Panchromatic | 450-800 |
| | Coastal Blue | 400-450 |
| | Blue | 450-510 |
| | Green | 510-580 |
| | Yellow | 585-625 |
| | Red | 630-690 |
| | Red-edge | 705-745 |
| | Near Infrared 1 | 770-895 |
| | Near Infrared 2 | 860-1040 |
| Sensor Resolution (m) ( GSD=Ground Sampling Distance) | Panchromatic | 0.46 |
| | Multispectral | 1.84 |
| Radiometric Resolution | 16 bits per pixel | |
| Sun Position | 48.1° and 161.7° | |

Appendix 5. Field data sheet

Field Data Sheet for Mapping and detection of the *Viscum album* in *Pinus sylvestris* in Bois noir, Barcelonnette, France

Date:

| | | | | | | |
|---|---|---|---|---|---|---|
| Sampling Method * | | | | | | |
| Forest Type | | | | Coordinates | X: | |
| Sample Plot ID | | | | | Y: | |
| Crown Coverage | East | West | Centre | North | South | Average |
| | | | | | | |

Slope (%): Aspect: Altitude:
Canopy Density: Average:
Reference Points: Bearing: Distance:

| S. N. | Tree ID | Species | D B H (cm) | Height (m) | Crown diameter (m) | Coordinate X | Coordinate Y | *Viscum album* level** | Forest Type | Distance from centre point | Bearing | Photo No. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | 321 | 491 | | | | | | |
| 2 | | | | | | 321 | 491 | | | | | | |
| 3 | | | | | | 321 | 491 | | | | | | |
| 4 | | | | | | 321 | 491 | | | | | | |
| 5 | | | | | | 321 | 491 | | | | | | |
| 6 | | | | | | 321 | 491 | | | | | | |
| 7 | | | | | | 321 | 491 | | | | | | |
| 8 | | | | | | 321 | 491 | | | | | | |
| 9 | | | | | | 321 | 491 | | | | | | |
| 10 | | | | | | 321 | 491 | | | | | | |

Note:

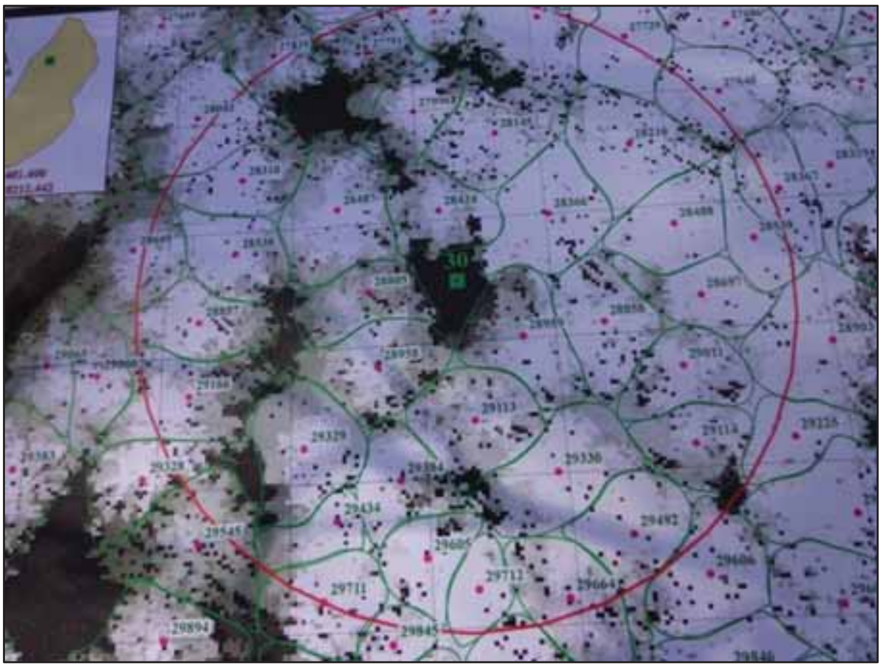
Sampling Type ** 1.Transect Line 2. Circular Plot

*Viscum album* level ** 0=No *Viscum album* 1=Low *Viscum album* 2=Medium *Viscum album* 3=High *Viscum album*

Appendix 6. Spatial location of sample plots

| Plot ID | Forest Type | POINT_X | POINT_Y | Average Elevation |
|---|---|---|---|---|
| P1 | Pinus sylvestris | 321557 | 4918741 | 1425 |
| P2 | Pinus sylvestris | 321542 | 4918626 | 1457 |
| P3 | Pinus sylvestris | 321604 | 4918617 | 1446 |
| P4 | Pinus sylvestris | 321692 | 4918632 | 1437 |
| P5 | Pinus sylvestris | 321426 | 4918417 | 1549 |
| P6 | Pinus sylvestris | 321481 | 4918331 | 1517 |
| P7 | Mixed Coniferous | 321324 | 4918270 | 1560 |
| P8 | Pinus sylvestris | 321444 | 4918265 | 1537 |
| P9 | Pinus sylvestris | 321550 | 4918268 | 1528 |
| P10 | Pinus sylvestris | 321841 | 4918215 | 1482 |
| P11 | Pinus sylvestris | 321401 | 4918212 | 1546 |
| P12 | Mixed Coniferous | 321220 | 4918215 | 1568 |
| P13 | Pinus sylvestris | 321191 | 4918141 | 1576 |
| P14 | Pinus sylvestris | 321271 | 4918140 | 1568 |
| P15 | Pinus sylvestris | 321380 | 4918135 | 1557 |
| P16 | Pinus sylvestris | 321737 | 4918081 | 1513 |
| P17 | Pinus sylvestris | 321514 | 4918098 | 1544 |
| P18 | Pinus sylvestris | 321252 | 4918050 | 1579 |
| P19 | Pinus sylvestris | 321435 | 4918039 | 1559 |
| P20 | Pinus sylvestris | 321761 | 4917987 | 1530 |
| P21 | Pinus sylvestris | 321678 | 4917975 | 1549 |
| P22 | Pinus sylvestris | 321392 | 4917990 | 1571 |
| P23 | Pinus sylvestris | 321328 | 4918008 | 1570 |
| P24 | Pinus sylvestris | 321208 | 4917911 | 1598 |
| P25 | Pinus sylvestris | 321256 | 4917879 | 1603 |
| P26 | Pinus sylvestris | 321313 | 4917878 | 1594 |
| P27 | Pinus sylvestris | 321410 | 4917893 | 1589 |
| P28 | Pinus sylvestris | 321691 | 4917919 | 1559 |
| P29 | Pinus sylvestris | 321513 | 4918463 | 1509 |
| P30 | Pinus sylvestris | 321401 | 4918212 | 1546 |
| P32 | Pinus sylvestris | 321382 | 4918365 | 1559 |

Appendix 7. LiDAR derived tree Canopy Height Model (CHM) of sample plot 30



(Source: Anahita & Collins)

Appendix 8. Descriptive statistics of the Bois noir

| S.N. | Species | No. of specimen | D | RD | F % | RF % | A | RA % |
|---|---|---|---|---|---|---|---|---|
| 1 | *Alnus viridis* | 2 | 1.29 | 0.16 | 3.23 | 1.30 | 2.00 | 2.93 |
| 2 | Broadleaf deciduous | 137 | 88.39 | 10.74 | 51.61 | 20.78 | 8.56 | 12.56 |
| 3 | *Fraxinus excelsior* | 37 | 23.87 | 2.90 | 19.35 | 7.79 | 6.17 | 9.05 |
| 4 | *Larix decidua* | 13 | 8.39 | 1.02 | 22.58 | 9.09 | 1.86 | 2.73 |
| 5 | *Picea abies* | 6 | 3.87 | 0.47 | 9.68 | 3.90 | 2.00 | 2.93 |
| 6 | *Pinus sylvestris* | 957 | 617.42 | 75.00 | 100.00 | 40.26 | 30.87 | 45.30 |
| 7 | *Pinus uncinata* | 103 | 66.45 | 8.07 | 29.03 | 11.69 | 11.44 | 16.79 |
| 8 | *Populas tremula* | 21 | 13.55 | 1.65 | 12.90 | 5.19 | 5.25 | 7.70 |
| | Total | 1276 | 823.23 | 100.00 | 248.39 | 100.00 | 68.15 | 100.00 |

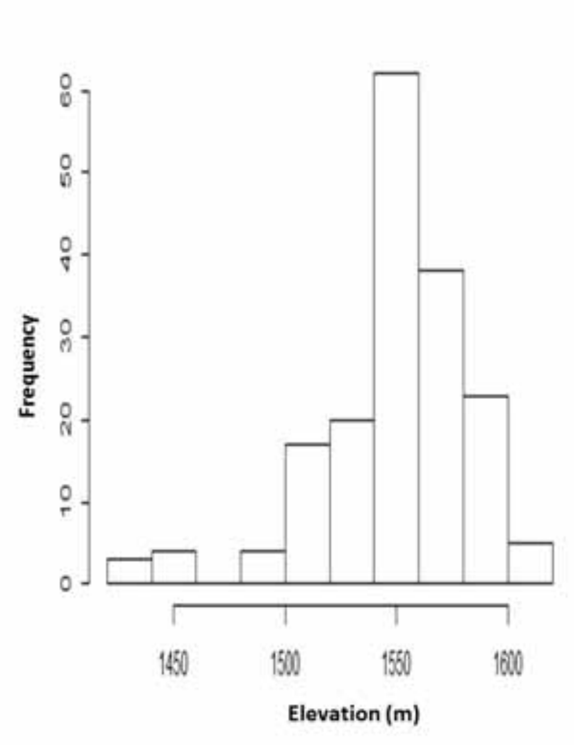
Where:

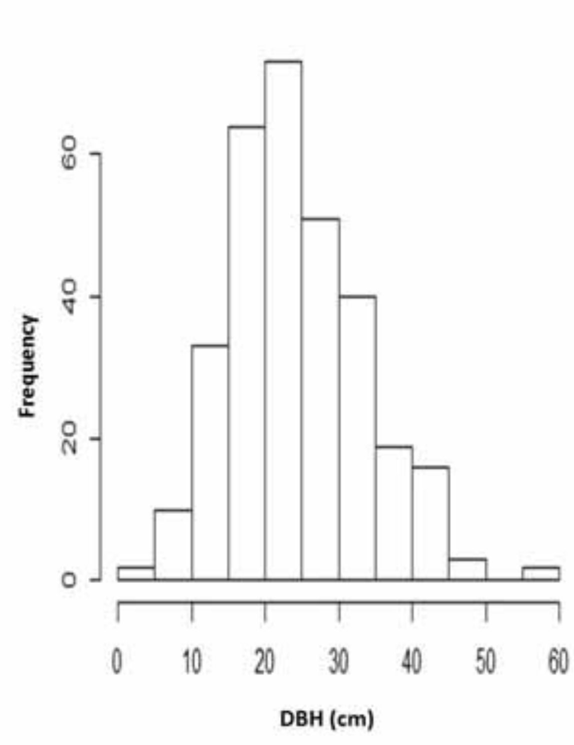
S.N. = Serial Number

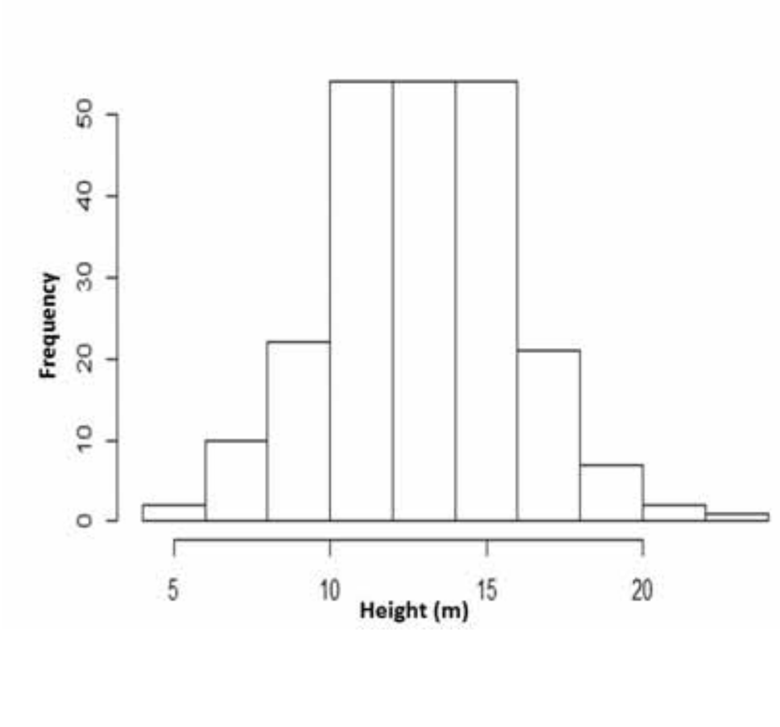
D= density, RD= Relative Density, F= Frequency,

RF= Relative Frequency A= Abundance , RA= Relative Abundance

Appendix 9. Histogram of *Pinus sylvestris* tree parameters



Appendix 10. Descriptive statistics of *Pinus sylvestris* tree parameter

| *Pinus sylvestris* | | | | | | | |
|---|---|---|---|---|---|---|---|
| Variable | n | Min | Max | Mean | Std. deviation | Median | Mode |
| DBH (cm) | 956 | 3 | 59 | 18.68 | 9.0 | 18 | 18 |
| Height (m) | 227 | 4 | 23 | 13.21 | 3.09 | 13 | 11 |
| Elevation (m) | 172 | 1423 | 1605 | 1550 | 34 | 1557 | 1568 |

Appendix 11. DBH class of *Pinus sylvestris*

| Tree Category | DBH Range | Tree number | % |
|---|---|---|---|
| Sapling | <10 cm | 161 | 16.8 |
| Pole | 10-30 cm | 681 | 71.2 |
| Sawlog | >30 cm | 114 | 12 |
| | Total | 956 | 100 |

Appendix 12. Descriptive statistics of presence and absence of *Viscum album* in *Pinus sylvestris*

| Status of *Viscum album* in *Pinus sylvestris* | No. of plots in which *Viscum album* Occurred | D (tree/ha) | RD (%) | F % | RF % | A | RA % | BA/ha | RBA |
|---|---|---|---|---|---|---|---|---|---|
| Presence | 17 | 40.6 | 6.6 | 54.8 | 35.4 | 3.7 | 11.4 | 3.3 | 16.1 |
| Absence | 31 | 577.4 | 93.4 | 100.0 | 64.6 | 28.9 | 88.6 | 17.5 | 83.9 |
| Total | | 618.1 | 100.0 | 154.8 | 100.0 | 32.6 | 100.0 | 20.8 | 100.0 |

Where,

D = Density RD= Relative Density F= Frequency;

RF=Relative Frequency A= Abundance RA= Relative Abundance

BA=Basal Area RBA=Relative Basal area

Appendix 13. Kappa statistics of classified species

| Species | Kappa (K^) |
|---|---|
| Pinus sylvestris | 0.8291 |
| Broadleaf | 0.9361 |
| Others | 0.7939 |

Appendix 14. Field pictures


*Pinus sylvestris* tree


Medium density *Viscum album* in Pinus sylvestris tree


Heavy density *Viscum album* in *Pinus*


Dying stage of *Pinus sylvestris* (*Viscunm album* on crown of the tree)

Difficulties in observation of *Viscum album* from ground due to high Dense canopy Cover
(Photo Courtesy: Anahita Khosravipur)


High density of *Viscum album* in *Pinus sylvestris* forest

Setting up the DGPS
(Photo Courtesy: Collins Kukunda)

Recording the co-ordinates of the sampling point

Author navigating the plot with iPAQ
(Photo Courtesy: Collins Kukunda)

Open field in the study area
(Photo Courtesy: Anahita Khosravipur)

Measuring DBH of tree


Dense pole size *Pinus sylvestris*

Research Team