Spectral Analysis of Worldview-2 Imagery in Detecting Invasive Plant Species (mistletoe) in Scots Pine Forest

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KEYWORDS

Biological invasion, Remote Sensing, NDVI, Optical satellite imagery

ABSTRACT

Mistletoe (Viscum album), a hemiparasite of Scots pine (Pinus sylvestris), is one of the major problems in the conservation of Scots pine forest in the Alps. The study area covered with coniferous plantation, a part of Bois Noir in the South Western French Alps is highly affected by mistletoe. Consequences of mistletoe infection include branch swelling and bending of the tree structure. The coniferous plantation in the study area, located in Bois Noir in the south-western French Alps, is experiencing an alarmingly high rate of tree mortality due to mistletoe infection. This study aims to assess the spectral distinctness of Scots pine in the presence and absence of mistletoe. For the management and minimization of biological invasion, detection and mapping plays a key role in forest conservation. 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 detecting, mapping and monitoring forest health. In this research, very high resolution satellite imagery WorldView-2 (panchromatic 0.5m and multispectral 2m) was used. Scots pine with mistletoe presence has low spectral reflectance in all bands, but NIR1, NIR2 and Red edge of WorldView-2 have higher ability to discriminate the mistletoe. Similarly, the vegetation index NDVI 2 (band combination of Red and NIR2) has the potential to discriminate the mistletoe. Detection of such biological invasions provides good information for effective conservation and better management of forests.

1. INTRODUCTION

Biological invasion poses a serious threat to global biodiversity and adversely affects native plants, ecosystem structure and function (Peerbhay et al., 2016; Thapa et al., 2018). *Viscum album austriacum* commonly known as mistletoe, is a threat to its host species and its widely growing infestation in various forests is exacerbating loss of tree species (Varga et al., 2012). By extracting water and carbohydrate from their hosts, mistletoe causes water and nutrient deficiency (Dobbertin et al., 2005a; Rigling et al., 2010). During the drought period, mistletoe effect can be as it increases the risk of drought induced mortality of its host species (Rigling et al., 2010). Eventually it disrupts the stomatal system including gas exchange effect (Zweifel et al., 2012) and thus reduces the photosynthesis phenomenon of the host species (Glatzel & Geils, 2009).

Mistletoe has a wide range of distribution in Asia and Europe (Hawksworth & Scharpf, 1986). It is widely distributed in the Alps and the dry inner alpine valleys to the north in Bavaria, where it has contributed to the decline of pine trees in the forests of Terul (Eastern Spain), France, Switzerland, Italy, Greece, Austria, Germany, Sweden, and Great Britain (Dobbertin & Rigling, 2006; Peršoh et al., 2010; Sanguesa-Barreda et al., 2012). Similarly, in Mexican cold mountain forest (evergreen coniferous forest), mistletoe is the second most destructive pest after the bark beetle (Clark-Tapia et al., 2011). In South-western French Alps, the tree mortality rate of planted *Pinus nigra* is also alarming due to mistletoe (Vallauri et al., 2002).

Pinus sylvestris (Scots pine) has been widely affected by mistletoe *and* is one of the major causes for its mortality (Mutlu et al., 2016). Crown degradation, ramification and radial increments are some of the impacts caused by the mistletoe to the host Scots pine (Rigling et al., 2010). The mortality rate of Scots pine infested by mistletoe is twice higher than that of non-infested trees (Dobbertin & Rigling, 2006). Swelling, bending of tree structure, and defoliation are some of the impacts which can be visually assessed in Scots pine with mistletoe. Furthermore, mistletoe is considered as an indicator species for changes in temperature as it causes drought stress in the host species (Dobbertin et al., 2005b).

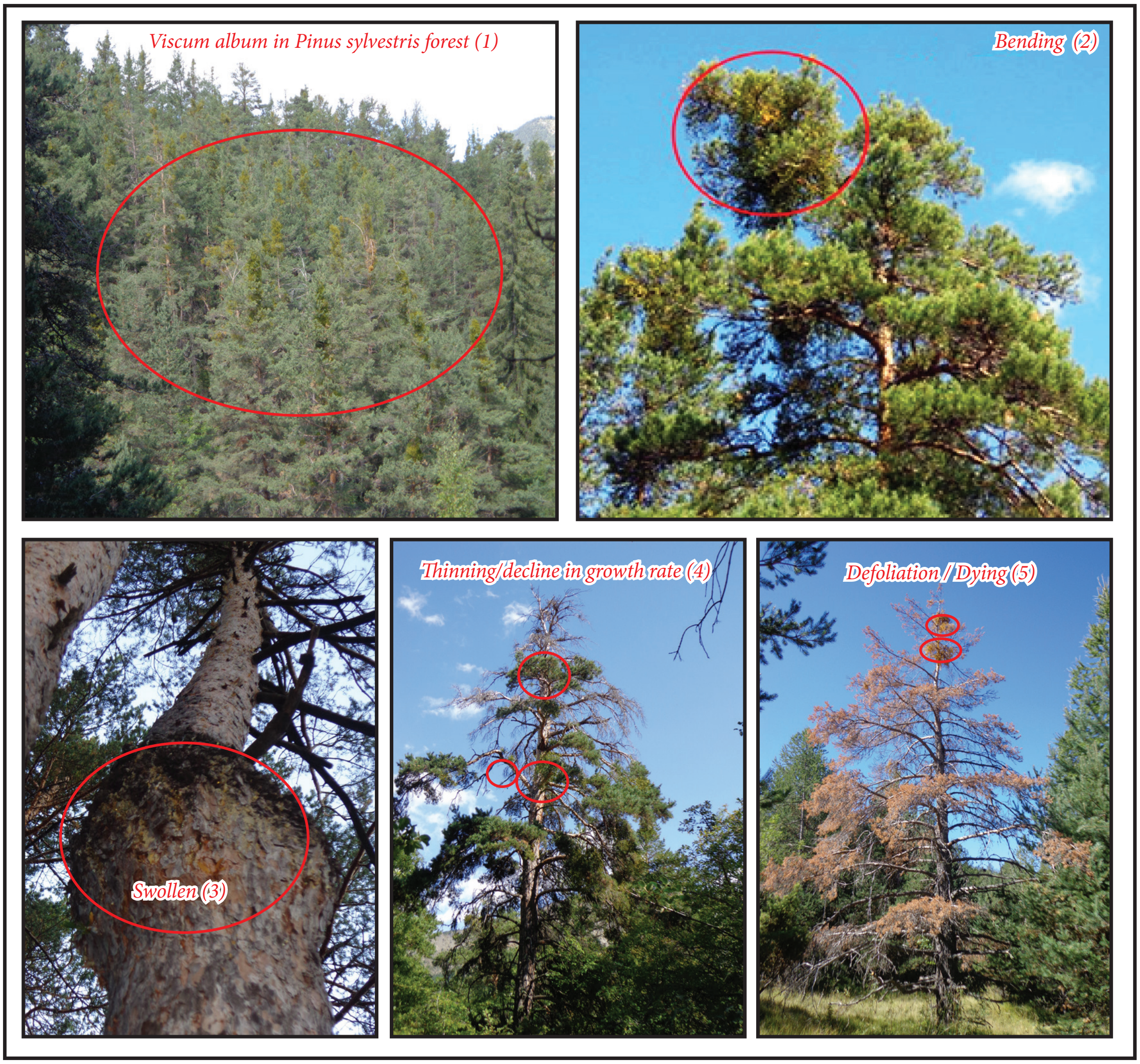

Figure 1: Impacts of mistletoe in scots pine trees in study area (Bois Noir, Barcelonnette France)

Remote sensing tools and technologies have been widely used in forestry. Remote sensing is an effective tool for detecting, monitoring and mapping forest health, pests and biological invasive species in forest (Joshi et al., 2006; Ismail et al., 2007; Peerbhay et al 2016). Twenty first century digital aerial imagery has the potential to capture the image between 5 cm 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. 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 for forest classification and monitoring.

Spectral reflectance and vegetation indices are the key indicators used for assessing and monitoring health of plants 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). The same species can respond differently according to their health condition (Carter & Knapp, 2001; Xie et al., 2008). 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 plant stress (Eitel et al., 2011), plant health (Xie et al., 2008), biomass (Mutanga et al., 2012), and crop production (Psomiadis et al., 2017). 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. 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).

2. MATERIALS AND METHODS

2.1. Study area

The study area is a part of Bois noir catchment located in the South Eastern part of France in the district of Barcelonnette. The study area is located between 44°25' 22.87''N latitude

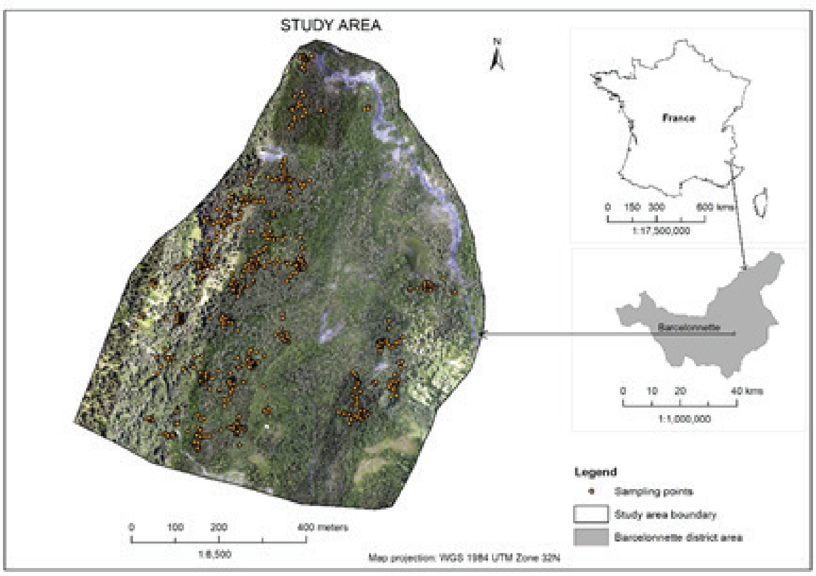

Figure 2: Study area showing distribution of sampling points

to 6°40’ 22.43’’E longitude with elevation ranges from 1100 to 3000 m. The climate of the study area is dry mountainous and inter annual rainfall strongly varies from 400 to 1400 mm and the mean annual temperature is around 7.5°C (Maquaire et al., 2003). The area has an irregular rugged topography with slope gradients ranging from 10° to 35° and scree slopes (Thiery et al., 2007; Saez et al., 2012).

The vegetation of the study area is a century old plantation of coniferous trees with pockets of broadleaf forests. 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 were initiated (Kappes et al., 2011). The area has relatively homogenous forest stands mostly dominated by conifers including Scots pine (*Pinus sylvestris*), Mountain pine (*Pinus uncinata*) and European larch (*Larix decidua*) along with some varied patches of mixed and broadleaved species.

2.2. Data

The WorldView-2 (WV-2) satellite is the first high resolution commercial satellite with 8 spectral bands (Digital Globe, 2009). It has a spectral diversity of 4 standard bands (Blue, Green, Red and NIR1) and 4 new bands (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). Very high resolution satellite imagery WorldView-2 (WV-2) of having 8 bands spectral resolution of 2m and panchromatic resolution of 0.5 m was used for this study. The imagery was acquired in September 2010.

The airborne Ortho imagery and airborne LiDAR data acquired in July were also used. The LiDAR derived canopy height model (CHM) and digital terrain model (DTM) were used.

2.3. Sampling design

A random set of 40 location points were generated in the study area. From the centre, the circular plot having 500m^2 areas was established to collect the data after slope correction (Husch et al., 2003). In order to increase the mistletoe incidence data 27 transects were sampled. Due to topographic constraints (steep slop and rugged terrain) 7 circular sample points were discarded and 2 plots without Scots pine trees were also removed from the sampling set. Only circular sample points were used for assessing the forest structure parameters like tree density and basal area (Boakye et al., 2012).

Field data collection was carried out from 11 to 27 September 2012. The iPAQ and Hand held 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 the 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 coordinates of the centre point of the plot.

Each Scots pine tree in the plots were visually assessed on the ground and incidence of mistletoe recorded. Crown coverage of the plot was measured using a spherical densiometer from five different locations within the plot and the canopy cover averaged. After sampling a circular plot, four 50 m perpendicular line transects were laid from the same centre point. The presence (P) and absence (A) of mistletoe in Scots pine trees was recorded at 5 m intervals.

2.4. Image preprocessing (Geometirc Correction)

The WorldView-2 image was delivered without any cloud cover, and both atmospherically and radiometrically corrected. Geometric correction was performed in two stages; (i) sensor specific geometric correction without ground control points and (ii) ortho-rectification using ground control points (Kukunda, 2013).

2.5. Extraction of canopy spectra of Scots pine in presence and absence of mistletoe from WV-2 image

Training samples of presence and absence of mistletoe in Scots pine were obtained using field observations as a reference. Pixel value of sample Scots pine trees was extracted from the spectral profile. The mean pixel values of Scots pine trees with and without mistletoe were plotted in Y axis and the eight spectral bands of WV-2 were plotted in the X-axis.

In order to minimize the error in the analysis of WV-2 imagery spectral reflectance of Scots pine with mistletoe presence due to the gap in the imagery acquired date and field data collection date, the field data was labeled on the density of mistletoe in scots pine which was given as follows:

Density class of mistletoe:

0=No mistletoe; 1=Low mistletoe;

2=Medium mistletoe; 3=High mistletoe

The spectral profile of each density class of mistletoe was extracted and analyzed.

2.6. Computing and analysis of spectral vegetation indices

Three equations using different band combinations for Normalized Difference Vegetation Index (NDVI) (Rouse et al., 1974) were computed (Table 1) in the model maker. Three different NDVI maps were generated. Field points of presence and absence of mistletoe 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 mistletoe in Scots pine was plotted in Excel and the analysis was conducted.

NDVI was calculated as follows:

$$NDVI = \frac{NIR - Red}{NIR + Red} \qquad (1)$$

NIR - reflection in the near-infrared spectrum

Red - reflection in the red range of the spectrum

Table 1. *NDVI Vegetation Indices*

S.N.	Abbreviation	Equation
1	NDVI 1	[(NIR1-Red edge)/(NIR1 +Red edge)]
2	NDVI 2	[(NIR2-Red)/(NIR2 +Red)]
3	NDVI 3	[(NIR2-Red edge)/(NIR2 +Red edge)]

3. RESULTS AND DISCUSSION

The overall density of Scots pine tree is 618 trees/ha whereas the density of Scots pine having mistletoe *is* 40 trees/ha. Around 3.5 ha of basal area is covered by Scots pine trees having mistletoe. The presence of mistletoe is low in Scots pine having low DBH, while those with big DBH have high mistletoe presence. In the sampled trees, 10% of Scots pine with mistletoe presence have DBH more than 30 cm while only 0.3% of Scots pine with mistletoe have DBH less than 15 cm.

3.1. Spectral analysis of Scots pine in the presence and absence of mistletoe

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. Spectral distinctness of Scots pine in the presence and absence of mistletoe is clearly observed in all eight bands of the WV-2 image. All bands showed a similar trend of spectral curve for both presence and absence of mistletoe in Scots pine. 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 Scots pine with and without mistletoe are clearer in the WV-2 imagery. 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 mistletoe. However, mistletoe presence shows a short sharp rise compared to Scots pine with mistletoe absence. The mean reflectance of the healthy Scots pine in the visible range (400-700 nm) was slightly higher than that of Scots pine with mistletoe whereas there was much higher mean reflectance in 700-1000 nm than that of mistletoe infected pine trees. Li et al., (2014) study on detecting citrus greening disease, also reflect that healthy samples reflectance is much higher in 700-1000nm than infected samples. Spectral reflectance of Scots pine trees in the presence and absence of mistletoe.

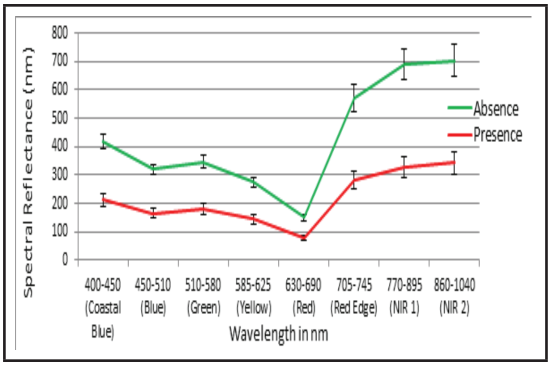

Figure 3: Spectral reflectance of Scots pine trees in the presence and absence of mistletoe

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, Scots pine with mistletoe presence may be under stress and photosynthetically less active compared to Scots pine with mistletoe absence. A study by Eitel et al. (2011) has shown that the Red edge band has the capability to detect plant stress due to changes in Chl_{ab};. According to Carter and Knapp (2001), transmittance, reflectance and absorptance of the stressed and healthy vegetation can be better distinguished in NIR. Red edge, NIR1 and NIR2 of WV-2 image plays a key role in class separability (Immitzer et al., 2012a) and additional spectral band of WV-2 detected coniferous and broadleaf trees with 99% accuracy (Immitzer et al., 2012b). Similarly, in this research the Scots pine with mistletoe 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.

3.2. Analysis of vegetation indices (NDVIs)

The mean NDVI pixel value of presence and absence of mistletoe was calculated (Table 2). In all three calculated indices, the NDVI ratio value is lower for Scots pine with mistletoe presence. However, NDVI ratio 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 mistletoe better compared to other two indices.

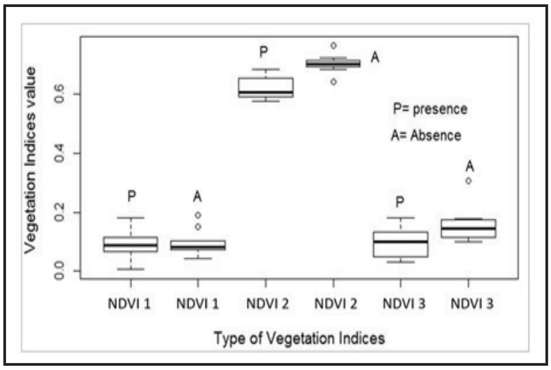

Figure 4: Boxplot of reflectance value of three different vegetation indices for presence and absence of mistletoe in Scots pine

Table 2.*Reflectance value of three vegetation indices*

	Mistletoe	
NDVI	**Presence**	**Absence**
NDVI 1	0.09	0.097
NDVI 2	0.619	0.704
NDVI 3	0.1	0.155

NDVI 2 was significant at (alpha=0.05, p-value<0.00) for discriminating the presence and absence of mistletoe in Scots pine. However, NDVI 1was not significant at alpha of 0.05. Furthermore, a Kruskal-Wallis test showed NDVI 2 was significantly different (p<0.0167) from NDVI 1 and NDVI 3. NDVI 2 had highest discrimination and was significantly different from other two vegetation indices. Ismail et al. (2006; 2008) also revealed that NDVI shows better performance compared to other vegetation indices in detecting Pinus patula tree infestation by Sirex noctilio. Similarly, previous research done by Bhattarai et al. (2011) has obtained a significant result (p-value =-0.09) to discriminate Sirex wood wasp infested Scots pine in WV-2 by using NDVI 2. NDVI 2 value of Scots pine trees was lower in the presence of mistletoe which indicates a reduction 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.

4. CONCLUSION

From the analysis of spectral characteristics of Scots pine in WV-2 image, it was revealed that there is a distinct spectral reflectance of Scots pine in the presence and absence of mistletoe. The Red edge, NIR1 and NIR2 bands of WV-2 show better separability. Among three vegetation indices, NDVI 2 showed the highest performance in distinguishing mistletoe in Scots pine. This kind of research is very limited in Nepal's forest so assessing the spectral distinctness of biological invasion in Nepal's forest could be beneficial.

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