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Monitoring Infestations of Oak Forests by *Tortrix viridana* (Lepidoptera: Tortricidae) using Remote Sensing

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Abstract

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We tested the suitability of Landsat images to track defoliation by insect herbivory with focus on the oak leaf roller, *Tortrix viridana* (Lep.: Tortricidae). Landsat images from the period before (2002) and after the *T. viridana* infestation (2007, 2014) were compared in oak forests of Zagros in western Iran. The Normalised Difference Vegetation Index (NDVI) was calculated for the test area from Landsat 5, 7, and 8 images. Because the red and near-infrared spectral bands of Landsat 8 OLI sensors are different from the other two, a model for the calibration of Landsat OLI NDVI was developed. The proposed model with a correlation coefficient of 0.928 and root mean square error of 0.05 turned out to be applicable and the NDVI decreased significantly during the observation period. Taking into account the protection status of the area and small fluctuations in temperature, the decrease in NDVI could be attributed to *T. viridana* damage.

Keywords: oak leaf roller; Marivan city; Landsat satellite; *Quercus brantii*; *Quercus infectoria*

Forests perform an essential role in maintaining the ecological balance and the forest health is a key indicator of ecological conditions prevailing in any area (Zhang & Chen 2007). In Iran, forests comprise an area of 12.4 mil. ha, covering 7.4% of the country. Compared to other countries, the proportion of forests is rather low in Iran, making the preservation of these forests important for the provision of adequate ecosystem services (Sagheb Talebi *et al.* 2004). Most insects that live in the forests are useful (Haack & Blyer 1993), but some of them pose major challenges to forest management. The green oak leaf roller, *Tortix viridana* L., for instance, is a common early season defoliator of oaks (Schroeder & Degen 2008). The eggs are deposited on twigs, hatch coinciding with bud burst in spring and the larvae feed on the young growing leaves (Ivashov *et al*. 2002). This monophagous pest can cause the complete defoliation of the trees affected (Fazeli & Abaei 1990; Yazdanfar *et al.* 2015). In Zagros forests, the insect affects the main oak species *Quercus brantii* and *Q. infectoria* in lower elevation areas and *Q. libani* at altitudes above 1700 m a.s.l. (Ghobari *et al*. 2007). The symptoms of damage to oak forests by the oak leaf roller are recognisable in many cases even from long distances. However, on-site monitoring of insect defoliation remains time- and cost-consuming. Therefore, alternative methods at a lower cost and with an acceptable level of accuracy are required. Remote sensing data, due to their wide coverage, their repeatability, and their ease of use, combined with field data have the potential to greatly facilitate the collection of information about insect damage. Quick access to remote sensing imagery has proved very valuable in identifying a disaster and also in planning and monitoring an emergency action. Remote sensing images are widely used in the study of forest mortality caused by pests, diseases

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and insects (Rullan-Silva *et al.* 2013). In general, previous studies covered a wide range of detection and mapping of a variety of forest pests. Vogelmann and Rock (1988) investigated damage caused by pear thrips (*Taeniothrips inconsequens* (Lep.: Thripidae)) and the capability of Landsat Thematic Mapper (TM) data for the detection of pear thrips outbreaks in deciduous forests. Kelly (2002) studied sudden oak death in California using high-resolution satellite images and demonstrated an overall accuracy of 92% in detecting oak death using Normalised Difference Vegetation Index (NDVI). Ismail *et al.* (2006) explored crown cover damage caused by *Sirex noctilio* (Lep.: Siricidae) using a series of ratio and linear based vegetation indices and showed that NDVI, as compared to the other vegetation indices, allows the best determination of the different crown conditions. In a study by Vogelmann *et al.* (2009), changes in forest health were investigated in the southern United States using the Landsat data over 18 years. The vegetation SWIR/NIR index showed a decrease of crown greenness (or an increase of tree mortality) over this period and provided evidence that the use of Landsat data is suitable to evaluate long-term developments of forest health. Meddens *et al.* (2013) detected tree mortality caused by bark beetles using single-date and multi-date Landsat imagery and concluded that both methods are reliable. Walter and Platt (2013) analysed the mountain pine beetle (*Dendroctonus ponderosae* (Lep.: Curculionidae)) infestation using multi-temporal analysis and found that the NDVI and Normalised Difference Moisture Index (NDMI) values declined after the pest outbreak.

The ability to detect insect damage using remote sensing depends on the degree of damage to the foliage that leads to discoloration of leaves and eventually to tree mortality (Wulder *et al.* 2006); in addition the precision of information depends on the different data sources, with each source offering different levels of detail in relation to pest infestations (White *et al.* 2006). Satellite imagery with medium spatial resolution, such as Landsat images are well-suited for forest health and disturbance monitoring on a landscape and regional scale because of their broad spatial extent, medium spatial resolution, and multispectral bands (e.g. Collins & Woodcock 1996; Franklin *et al.* 2003; Skakun *et al.* 2003). In addition, the complete archives of multi-temporal Landsat imagery are freely available through USGS.

The detection of pest infestation using remote sensing is based on changes in the foliage amount and tree canopy structure (Entcheva *et al.* 1996), thus by altering the recorded tree reflectance spectrum. So, the forest health status can be determined through reflectance measuring.

Vegetation indices, especially NDVI, have been successfully used for various ecological purposes for several decades, because of their direct correlation with vegetation productivity (Walter & Platt 2013). The NDVI index is based on the fact that the chlorophyll in leaves absorbs electromagnetic radiation in the red region of the spectrum, which is proportional to the leaf chlorophyll concentration and the mesophyll structure of leaves highly reflects the near infrared (NIR) wavelength, which corresponds to green leaf density. The index values are between the numbers +1 and –1. Negative values for this indicator represent the absence of green vegetation (Tucker 1979; Pettorelli *et al.* 2005). The NDVI reacts to the change in the amount of biomass, chlorophyll content and water tension in the canopy, and the declining health status of trees leads to a reduction of canopy reflectance.

From a forest management perspective, information on the process of oak leaf roller infestation in Zagros forests is critical for forest management activities. There is very little information on the outbreaks of this pest in these forests. Therefore, the main objective of this study is to monitor the infestation by the oak leaf roller *T. viridana* in the part of Zagros forests using Landsat images.

MATERIAL AND METHODS

Study area and field data collection. The study area is located in the research station of Garan in the west of Iran (Figure 1). The Garan forestry research station has been fenced and highly controlled for more than 40 years to study oak forest succession dynamics by the Agriculture and Natural Resources Research Centre of Kurdistan, Iran. Average annual precipitation in the area is 997.6 mm, and average annual maximum and minimum temperatures are 41 and –27.5°C, respectively (Kurdistan Regional Climate Centre, Garan Station). Average elevation of the area is 1492 m a.s.l. The main forest species in the study area are predominantly *Quercus branti* and *Quercus infectoria* as well as other occasional tree species including *Acer monspessulanum*, *Amygdalus* spp., *Crataegus* spp., and *Pistacia mutica* (Anonymous 2010).

A field campaign was carried out in May 2014. We applied a purposive sampling approach aimed

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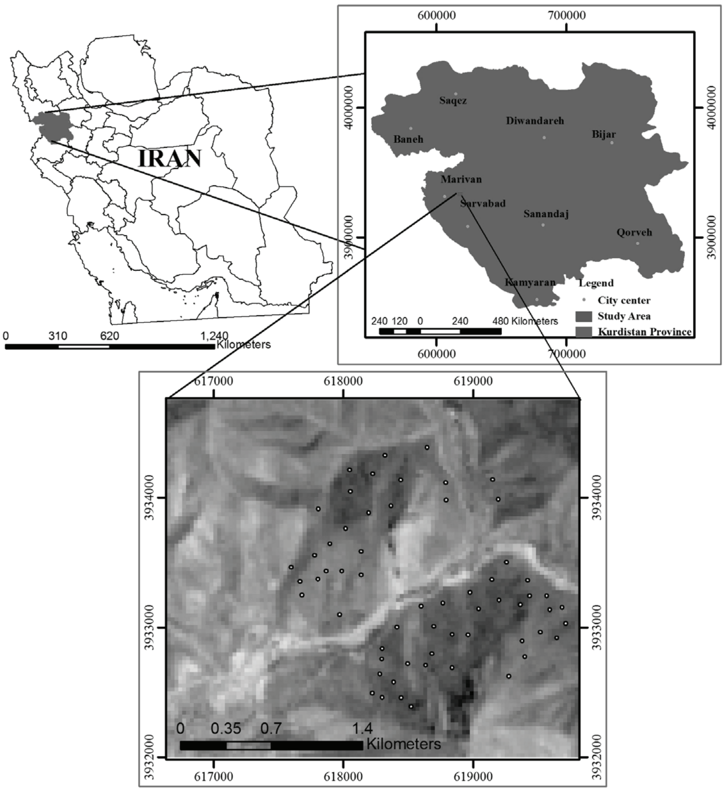

Figure 1. Study area localisation in Kurdistan Province, Iran

to capture a large range of tree conditions across the study area. 60 field reference points of infested forests were recorded with a GPS device.

Data acquisition and preprocessing. Three dates of Landsat TM and Operational Land Imager (OLI) Level 1 terrain-corrected (L1T) images related for Worldwide Reference System Path/Row: 168/35 (May 2002, 2007 and 2014) were downloaded from the USGS GLOVIS website (http://glovis.usgs.gov).

These images cover the year before as well as after the outbreak of the oak leaf roller. Landsat 7 Enhanced Thematic Mapper (ETM+) images of June 16, 2013 and Landsat 8 OLI images of June 8, 2013 were downloaded for the calibration of NDVI. In order to reduce the variation between data scenes due to sun angle, atmospheric conditions, and differences in vegetation phenology, the images of the same time (May) were selected (Hayes & Sader 2001).

Landsat 7 ETM+ and Landsat 8 OLI were converted to TOA reflectance based on the available calibration coefficients and standard formulas (http://landsat.usgs.gov/Landsat8_Using_Product.php; Chander *et al.* 2009).

Atmospheric correction, especially in evaluating and comparing the images of two or more times is necessary because of the differences in atmospheric effects according to time and place. To compare the reflectance of images, radiometric normalisation is necessary. The Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) correction method was used for the atmospheric correction of images (Chavez 1996, 1988) and a linear regression was applied using digital numbers of targets in the base image against digital numbers of targets in other images in order to normalise them (Kelly 2002).

NDVI generation. Normalised Difference Vegetation Index at a resolution of 30 m was calculated for each of the Landsat 8 OLI, Landsat 5 TM and Landsat 7 ETM+ images (Eq. 1), based on red and near-infrared TOA reflectance.

$$NDVI = (NIR - R) / (NIR + R) \quad (1)$$

where: R, NIR – Top-of-Atmosphere reflectance in the red and near-infrared band, respectively.

Comparisons of NDVI between Landsat 8 OLI and Landsat 7 ETM+. Since the spectral range of Landsat 8 OLI is narrower than that of Landsat 5 TM or Landsat 7 ETM+ (Figure 2), NDVI derived from them have different values. This difference makes it impossible to compare the two directly. To solve this problem, the indices from these two sensors have to be calibrated. We thus identified the relationship between NDVI derived from two sensors, and developed a model for the calibration of the Landsat OLI derived NDVI.

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Table 1. Regression analysis for the Normalised Difference Vegetation Index (NDVI) calibration for two sensors

Model	Coefficient	Standard error	Significance level	Bias	Bias%	RMSE	RMSE%
Constant	–0.266	0.03	< 0.01	0.03	0.19	0.05	0.27
NDVI Landsat 8	0.966	0.089	< 0.01				

R^2 = 0.928; R^2_{adj} = 0.853

A prerequisite for model development is the availability of two comparable and simultaneous NDVI images. Two images with the least time difference (8 days) were used and the NDVI index was generated for Landsat 7 ETM+ (June 16, 2013) and Landsat 8 OLI (June 8, 2013). Twenty-one points were extracted from NDVI time-series and the possibility of developing a regression model was examined. The model validation was done with 10 control samples that were not used in model development based on Root Mean Square Error and Bias (Makela & Pekkarinen 2004). This model was applied to values of Landsat 8 OLI NDVI to make it comparable with Landsat 5 TM and Landsat 7 ETM+ NDVIs.

Statistical analysis of NDVI changes in different years. After extracting NDVI values for each of the sample plots of the infested forests by oak leaf roller in three years (2002, 2007, and 2014), the normality of extracted values was investigated using the Kolmogorov-Smirnov normality test. Then, the paired sample t-test was used to statistically analyse differences between NDVI of three years.

RESULTS

Regression model development for NDVI calibration. Figure 3 presents NDVI images of the study area from three years (2002, 2007, and 2014) that were generated to investigate the infestation by oak leaf roller *T. viridana* in the part of Zagros forests using Landsat images.

The results of the development of a regression model for NDVI calibration of OLI and ETM+ sensors are shown in Table 1. The regression model with coefficients of determination (R^2) of 0.928 and root mean square error (RMSE) of 0.05 demonstrated that NDVI obtained from Landsat7 ETM+ and Landsat8 OLI were highly linearly correlated. No significant bias was detected (t = 1.02), showing the suitability of the model.

The regression model was applied to the NDVI of Landsat 8 OLI to make it comparable with the NDVI of Landsat 7 ETM+ or Landsat 5 TM.

Comparison of changes in NDVI in different years. Comparing NDVI values obtained before the infestation by oak leaf roller (2002) and after it (2007 and 2014) showed a statistically significant decrease of NDVI in the years after the infestation.

The Kolmogorov-Smirnov normality test results indicate that all NDVI data are normal (Table 2). The paired sample t-test results showed that there is a statistically significant difference between NDVI in the years 2002 and 2007, and also between 2007 and 2014 (Table 2). In 2014, the outbreak of oak leaf roller was worse than in 2007 and the results confirm this.

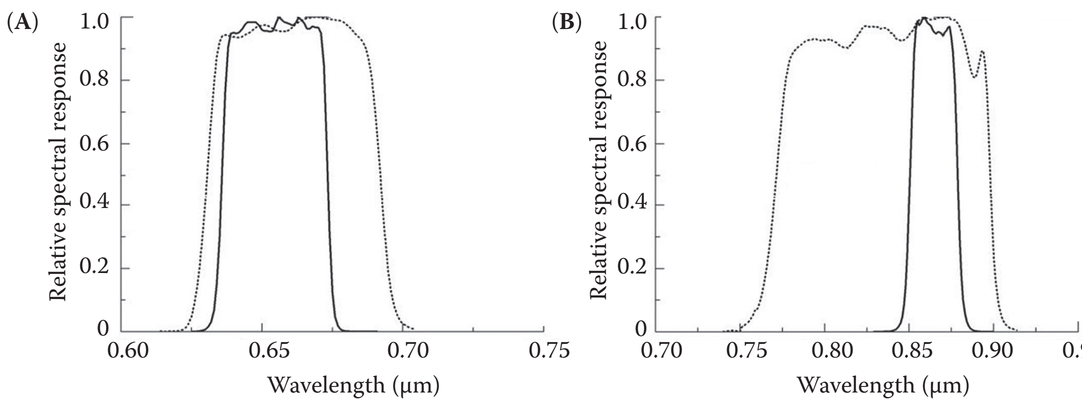

Figure 2. The red (**A**) and near-infrared (**B**) spectral band difference between Landsat 8 OLI (solid curve) and Landsat 7 ETM+ (dotted curve) [provided by the US Geological Survey (USGS) http://landsat.usgs.gov/tools_spectralViewer.php]

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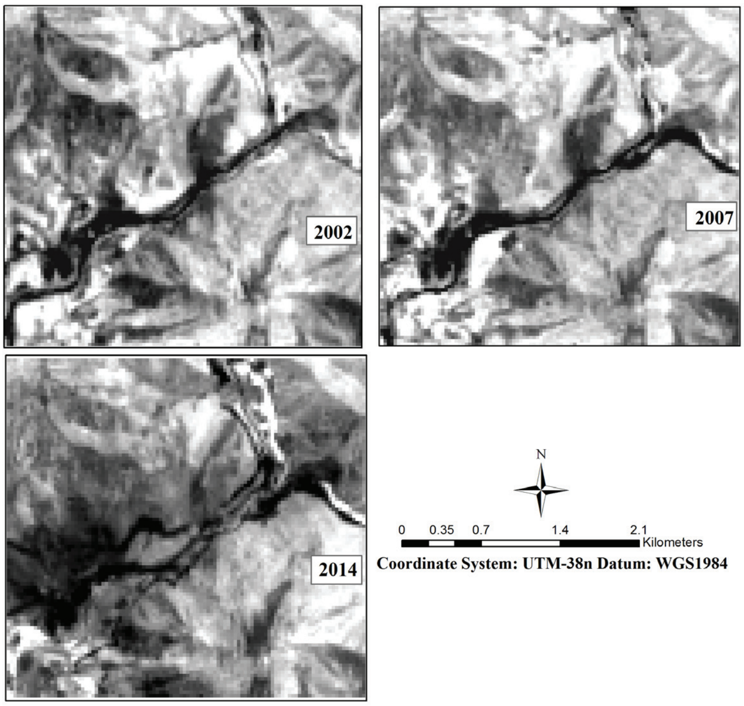

Figure 3. NDVI images in the years before (2002) and after (2007, 2014) the oak leaf roller infestation (lighter pixels = high NDVI values, darker pixels = low NDVI values)

Table 2. The results of Kolmogorov-Smirnov normality test

Year	Index	Z	*P*
2002	NDVI	0.882	0.418
2007	NDVI	0.681	0.742
2014	NDVI	0.512	0.955

Table 3. The comparison of Normalised Difference Vegetation Index (NDVI) means in three years

Time period	Index	*t*	*P*
2002–2007	NDVI	10.411	> 0.01
2007–2014	NDVI	9.580	> 0.01

DISCUSSION

Interventions and excessive human exploitation, along with climate change lead to environmental problems such as disruption of the ecological balance and pest outbreaks. Oak leaf roller is one of these pests causing great damage to Zagros oak forests (Ghobari *et al.* 2007; Yazdanfar 2015). In order to detect and monitor the harmful effects of leaf roller infestation, remote sensing knowledge was used as a new tool in environmental monitoring. The date of imagery acquisition is important for the success of the monitoring (Kelly 2002). The activity of oak leaf roller on leaves and buds could obviously be distinguished in May, so the related images were used.

Comparison between Landsat 8 and the earlier Landsat (Landsat 7 and 5) is highly important for change detection, since the Landsat satellites have collected imagery for many years (Li *et al.* 2013). The regression model that was developed for Landsat 8 NDVI calibration with high coefficients of determination (R^2 = 0.928) is suitable for converting OLI derived NDVI to comparable NDVI of ETM+ and TM. Li *et al.* (2013) also pointed to the high linear correlation coefficient (R^2 > 0.96) of vegetation indices derived from ETM+ and OLI imagery.

The NDVI decreased significantly in the years after infestation, because the NIR band reflectance decreased significantly after infestation (Rock *et al.* 1988; Junttila *et al.* 2015).

Wang *et al.* (2003) stated that the relationship between NDVI and temperature at the beginning and end of the growing season is positive. Therefore, in this study, changes in temperature in the months of April and May in 2002, 2007, and 2014 were investigated. The results showed that the temperature measured at the beginning of the growing season did not much change in three years – the average temperatures of April were 11.4, 11.8, and 13.1°C and of May 16.6, 18.3, and 18°C for the years 2002, 2007, and 2014, respectively (Kurdistan Regional Climate Center, Garand Station; http://www.kurdistanmet.ir/).

The amount of rainfall in 2007 increased when compared to 2002 (Kurdistan Regional Climate Center, Garan Station); despite this increase in rainfall, the NDVI decreased in 2007. Moreover, interference with

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human activities and livestock grazing are so limited in this protected area. Therefore, decreasing NDVI can be associated with a high probability of defoliation by the oak leaf roller. A study on sudden oak mortality in California using high-resolution images and NDVI also revealed an NDVI decrease after the onset of epidemic pest infestation (Kelly 2002). The study of Ismail *et al*. (2006) investigating the damage to forest canopy due to *S. noctilio* using different vegetation indices suggested the suitability of NDVI for the diagnosis of the situation. Also in North Sweden, an outbreak of *Epirrita autumnata* (Geometridae) was associated with a pronounced decline of the NDVI derived from Landsat images (Babst *et al*. 2010), confirming the suitability of this index for the detection of pest infestations in forests. Additional evidence of NDVI usefulness for forest health monitoring was provided by Sader and Jin (2006) and Walter and Platt (2013).

To date, NDVI has been the most frequently used and so proven vegetation index for monitoring the pest infestation (Rullan-Silva *et al*. 2013). Our research collaborates these findings for *T. viridana* infestations in oak forests.

It is worth noting that remotely sensed imagery using NDVI index to assess the outbreak effect on the tree condition has some limitations: (*i*) NDVI tends to saturate at high canopy closer, (*ii*) it is highly sensitive to the understory and soil background signal, and (*iii*) optical remote sensing data in general are sensitive only to the upper part of tree canopy, therefore changes in the lower part of canopy can hardly be detected (Meigs *et al*. 2011).

Another limitation of our study was the unclassified defoliation damage severity in some classes such as low, middle, high and very high, because of the lack of field information about the rate of defoliation severity.

According to the results obtained in this research, and considering that the area is protected, and the poor effect of other factors, it could be concluded that the significant decrease in NDVI in the years after infestation is a sign of the oak leaf roller damage to leaves and buds of the oak trees.

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