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VARIATION IN FOREST COVER DUE TO FIRE IN SIERRA DE LA VENTANA, PROVINCE OF BUENOS AIRES, ARGENTINA

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ABSTRACT: Fires are events that occur regularly in the Sierra de la Ventana region, affecting native and exotic herbaceous and exotic arboreal vegetation (mainly Pinus pinaster and Pinus halepensis). Although they are disturbances ecologically adapted to the environment, the advance of exotic vegetation and the perception of the population has modified their frequency and intensity. The objective was to identify the variation in forest cover due to fires in the Arroyo Ventana Basin, Province of Buenos Aires, covering the period 2010-2020. Two large fires were identified: 2013 and 2018. A land use map was developed through supervised classification of satellite images Lansat8 and Sentinel2. Likewise, satellite images were used for the dates before and after the events, processed with the QGIS Madeira 3.4.6 software. Vegetation indices Burned Area Index (IAQ) and Normalized Difference Vegetation Index (NDVI) were applied. It was obtained that the variation of forest cover does not exceed 30 ha in the studied period (minimum 140ha, maximum 170 ha), although its distribution does change, a spatial variation that corresponds to the burned areas. Abundant regeneration was observed between the years 2013 and 2017. The fires have proven to be controllers of the forest cover, maintaining a stable surface in the period studied. However, this process is a triggering factor for the germination and subsequent establishment of regeneration of *Pinus sp*.

KEYWORDS: Fires; regeneration; pinus; environment

INTRODUCTION

Studies on the dynamic processes of land cover change are important and necessary, because they provide the basis for understanding the trends of degradation, desertification and biodiversity loss processes in a given region (Van Lynden & Oldeman, 1997). In the mountainous area of the southwest of the Province of Buenos Aires (Argentina), surface water erosion causes a decreasing agricultural production, as a consequence of the current soil management, the loss of the surface horizon and the availability of surface and subway water. In recent decades, given the productive capacity of the soils in this region, Pampean grasslands have been replaced by agroecosystems and show significant degradation and a low degree of conservation (Vázquez & Zulaica, 2011).

Numerous woody species were introduced to enrich the natural landscape of the area, which have managed to establish self-sustaining populations that adapt to the ecology of the site, reproduce autonomously and have the ability to colonize new sites, such as the mixed forests of *Pinus. Radiata* D. Don (Monterey pine) and *Pinus halepensis* Mill. (Aleppo pine), being considered invasive species.

In areas where pines invade, fire plays a primary role in the process of establishment and expansion of their populations. However, it is not an exclusive factor, since other ecological conditions can favor the advance of this invasive species. In the PPET, continuous grazing by bighorn horses reduces competition for light and favors the establishment of pine seedlings in the mountain pastures, even in the absence of fire. The results also indicate the importance of fire as a key factor in triggering the invasion of *Pinus halepensis* in the natural grassland environments studied (Villalobos, 2009).

The comparison of the reproductive performance of the species in the invaded area with respect to its native range of distribution allows postulating two main aspects, the greater weight of seeds and their possible influence on the establishment of seedlings and the absence of natural enemies, mainly seed predators, as biological hypotheses to understand the process of advancement of the species (Cuevas, 2011). After a fire, an important seed bank is formed in the soil, which is free of vegetation cover and is enriched in some nutrients and favored by predisposing climatic conditions, providing a recruitment opportunity for seedlings and resulting in a stand of pine trees of similar age. The ability of adult trees to survive low intensity fires and to generate a large recruitment of saplings after fires means that they not only resist this type of fire, but also facilitate the regeneration of the species (Fernández, 2010).

Zalba & Cazzaniga (2002) mention that, in 27 years, the surface area of these forests has increased more than tenfold; fire could have triggered the expansion, given that heat promotes the release of seeds from pine cones, reducing the competitive capacity of the grassland after a fire. To this situation, Michalijos (2018) expresses that it is added that the area is experiencing a large urban growth on forest areas accompanied by infrastructure development, product of the tourism boom.

Fires are a natural component of the Pampean grassland ecosystem. However, the advance of urbanization over natural areas has led society to consider them a disturbance that must be controlled. Human, by advancing over forest areas and trying to reduce the effects of fires, has altered their frequency, intensity and extent. The Sierra de la Ventana region is no stranger to this situation, and fires are recorded annually with increasingly worrying effects. This site has naturally suffered fires throughout its history, but in the last 20 years the occurrence has been greater and has had negative consequences for society. The result is a subsequent occurrence of fires with catastrophic characteristics for both the ecosystem and society. An example of this is the fire unleashed on December 29, 2013, caused by negligence, and considered the largest in the history of the Province of Buenos Aires, which is supposed to have affected 29,005 hectares, and caused material and economic losses to agricultural producers and owners of tourist ventures (Michalijos, 2018).

Michalijos (2018) states that the risk of occurrence of forest fires in the Sierra de la Ventana Shire is due to the high load of available fuel, the meteorological and topographic conditions that favor the spread of fire, the increase of constructions in forest areas and advance of urbanization, which modify the natural fire cycle.

Finally, Michalijos (2018) states that a notorious recovery of vegetation is evidenced a few months after the fire was extinguished, the consequences on biodiversity are negative and manifest over time. Exotic species advance over the natural grassland producing modifications in the dynamics of the ecosystems and modifying the frequency and intensity of fires. When the impact of the forests on the native flora of the reserve was measured, it was observed that the trees produce reductions in the total number of plants compared to the natural grassland control areas. In addition, the presence of tree species leads to significant increases in the proportion of exotic herb and shrub species. In other words, not only do fewer plants grow under the forests than in the grasslands, but the presence of exotic species favors other exotic species that find in the understory a favorable environment for their development, which could be the starting point for future invasions into the less transformed areas of the reserve (Zalba. 1994). In addition to these problems, the local population believes that the mountain ecosystem recovers quickly because the vegetation regenerates in just a few months. According to them, those who are really affected are the owners of tourist ventures who see a decrease in the influx of tourists during the period of vegetation recovery (Michalijos, 2018).

Therefore, the objective was to identify the variation in forest cover due to fires in the Arroyo Ventana Basin, Province of Buenos Aires, covering the period 2010-2020.

METHODOLOGY

The study area for the present work corresponds to the Ventana Basin (38° 01′ & 38° 07′ S; 61° 57′ & 62° 08′ W) (Gaspari et al., 2009), whose headwaters are located in the Parque Provincial Ernesto Tornquist, which covers an area of 6,718 hectares and is part of the Natural Areas System of the Province of Buenos Aires.

Land use mapping

The interpretation of vegetation cover and land use was carried out and represented by means of zoning on T20HNC images from the Sentinel2 satellite, for which we proceeded to its spatial reprojection and atmospheric correction. The RGB 843 composition was used, as it was considered adequate for identifying and zoning the crop management factor map and different coverages in the basin. Likewise, Google Earth images were used to visualize by date of flowering of shrublands (broom with yellow flowers) and wooded areas to apply in a supervised classification. Agricultural crops were identified by their representation in the satellite images, and very noticeable variations in vegetation were also observed in different satellite images. Those with conservation practices were discriminated by observation of contour lines in the images.

After obtaining all the polygons corresponding to each land use, they were processed using QGis Madeira 3.4.6. software, applying geometric correction and subsequent joining of the polygons, finally obtaining a single map that integrates all the land uses within the limits of the study area. Finally, we proceeded to calculate the surface areas for each land use and its percentage representation relative to the total surface area of the study area.

Using the United States Geological Survey (USGS) server (https://earthexplorer.usgs.gov/), satellite images from Landsat 8 (OLI images) and Sentinel 2 satellites were searched and downloaded by date and satellite, using images from one or the other, or both, according to the dates before and after the event.

Likewise, the use of Sentinel 2 images was preferred over Landast 8 images due to their higher spatial resolution (10 meters vs. 30 meters), obtaining greater detail for the evaluation of study areas as well as being able to identify different land covers. The use of Landsat 8 images was for dates when Sentinel 2 images were not available (prior to 2015). The main limitation that was found was the presence of cloud cover that interfered with the study area, having to opt for the use of cloud-free images from one or another satellite according to availability.

Due to their temporal, spectral and radiometric resolution characteristics, they are suitable for the study of vegetation cover variation. The images were preprocessed using QGis Madeira 3.4.6. software, with which they were atmospherically corrected, thus obtaining reflectance values.

Calculation of Vegetation Indices

In order to estimate the areas affected by fires, as well as their vegetation indexes in each affected area, the following spectral indices were calculated on the images corresponding to the study area:

Burned Area Index (IAQ) defined by Martín (2001) and recommended by Michalijos (2013) as the best index to estimate areas affected by fires in the mountainous area of the Ventania System. It was created specifically for the discrimination of burned areas, it is based on the distance established between each pixel and its reference spectral value, to which recently burned areas tend to converge. It is calculated from satellite image bands in the red and near infrared range according to Equation 1. The index value will be higher the smaller the spectral distance, that is, the more similar it is to that cover.

$IAQ=1/((Rq - R)^2 + (IRCq - IRC)^2)$ Equation 1

where IRCq and Rq= reference reflectivities (in near infrared 0.06 and red 0.1) of a known burned area and R= red and IRC= near infrared.

Normalized Difference Vegetation Index (NDVI), which has been widely used to discriminate burned areas (Pereira et al., 1997). In the present work it was used to study the variation of vegetation in the time elapsed after the fire, as well as to identify the capacity of the vegetation to recover. It was calculated using Equation 4.

$NDVI = IRC - R/IRC + R$ Equation 2

where IRC= near infrared R= red.

For each fire, satellite images were used to detect the different coverages, especially the variation in tree cover, which, together with shrubland, are the coverages that vary the most over the years and show the greatest regeneration dynamics due to the effect of the fires.

Using Sentinel 2 satellite images and Google Earth images (which have a good spatial resolution, allowing us to observe the existing cover in detail and in natural color), we plotted polygons of areas with forest presence for 4 points in time: 2010, 2013, 2017 and 2020. Based on these data, a supervised classification was performed with the QGis Semi Automatic Classification add-on, providing NDVI values corresponding to the cover in question. In this way, tree cover was differentiated from shrub cover, also comparing with Google Earth images for the flowering date of the broom (November), which in natural color shows its characteristic yellow color. This also served to plot polygons corresponding to this cover.

The choice of these moments represents inter-periods of equal or similar time, and corresponds to the initial and final moments of the period, as well as moments prior to the fires studied, being able to determine tree cover affected by them.

RESULTS

Search of satellite images corresponding to the dates of fire events

In the two events studied (2013-2014 and 2018), satellite images were used prior to the event called Moment 1 (M1); immediately after, called Moment 2 (M2); and after the last ones called Moment 3 (M3). Thus, the moments used in each event were:

2013-2014 fire: Landsat images (OLI) were used for events occurring between December 29, 2013 and January 05, 2014.

M1: December 23, 2013.

M2: January 08, 2014.

M3: March 20, 2014.

2018 fire: Sentinel 2 images were used for events that occurred between February 02, 2018 and February 14, 2018.

M1: January 07, 2018.

M2: February 26, 2018.

M3: December 18, 2018.

The M3s present a different M2-M3 time period for each event. This is due to the fact that for the 2018 event the time for vegetation recovery is not enough due to the coming autumn, i.e., a period where significant changes in vegetation can be identified.

For a better interpretation of the results obtained for each event, the fires studied are presented separately.

Comparison between NDVI values at the times studied

As shown in Figures 1 and 2, there was an early recovery of the affected area due to the regeneration capacity of herbaceous plants ecologically accustomed to fires. Thus, comparatively, sites with even higher NDVI values post-fire than pre-fire are observed. Likewise, sites corresponding to surface rock or grasslands with rock do not recover their NDVI values. Variations in values in agricultural crop areas are due to harvesting and planting times of the respective crops.

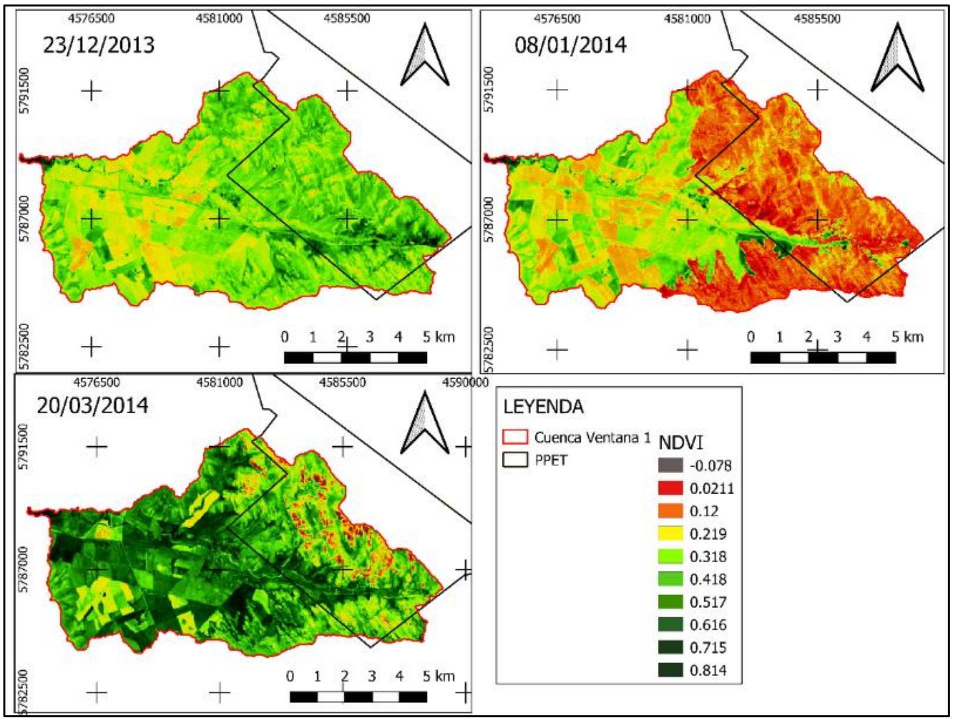

Figure 1. NDVI variation in three moments. Moment 1: before the fire, 12/23/2013 (top left). Moment 2: post-event, 08/01/2014 (top right). Next month, 20/03/2014 (bottom).

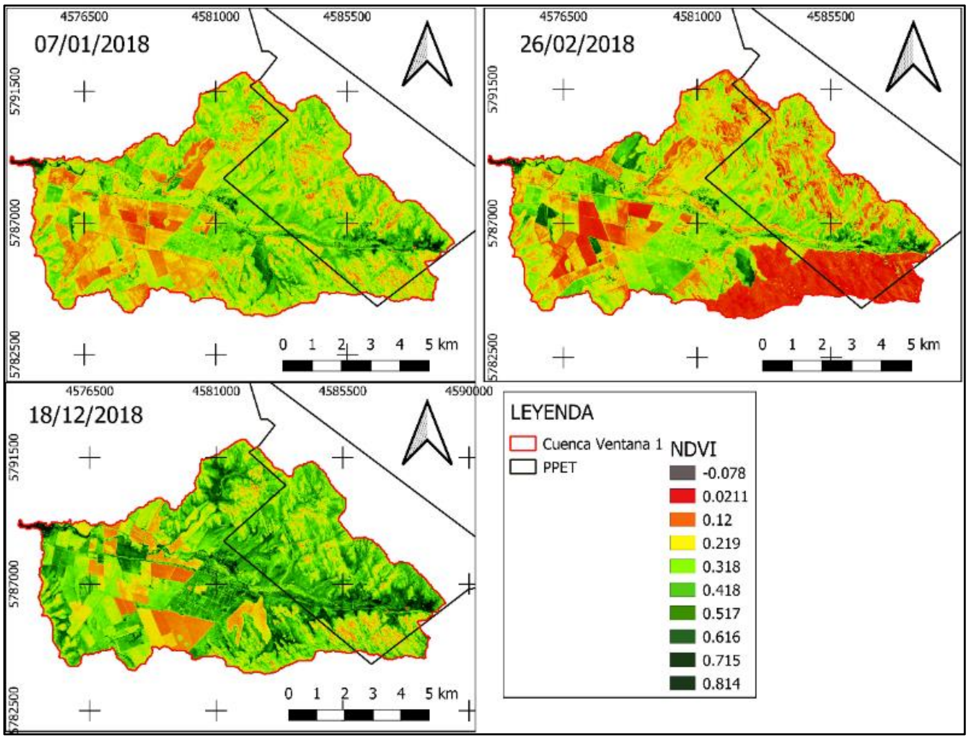

Figure 2. NDVI variation at three moments. Moment 1: pre-fire, 07/01/2018 (top left). Moment 2: post-event, 02/26/2018 (top right). Spring following, 12/18/2018 (bottom).

Variation of NDVI values in the period 2016-2020

First, with the calculation of NDVI values for the indicated years, a composition was obtained (Figure 3) where the variation of NDVI values can be observed. It stands out, at first glance, higher values throughout the area for the year 2016, probably linked to the recurrent rainfall recorded in the months prior to the time of the image (January 2016). Likewise, the lowest values correspond to the year 2018, the month prior to the fire studied. Probably these low values could correspond to increased danger of ignition in the area, having as a backup what happened at the site later, highlighting that if the fire had not been fought as it was, the flames would have safely passed Provincial Route 76, affecting a much larger area (as happened in the 2013 - 2014 event).

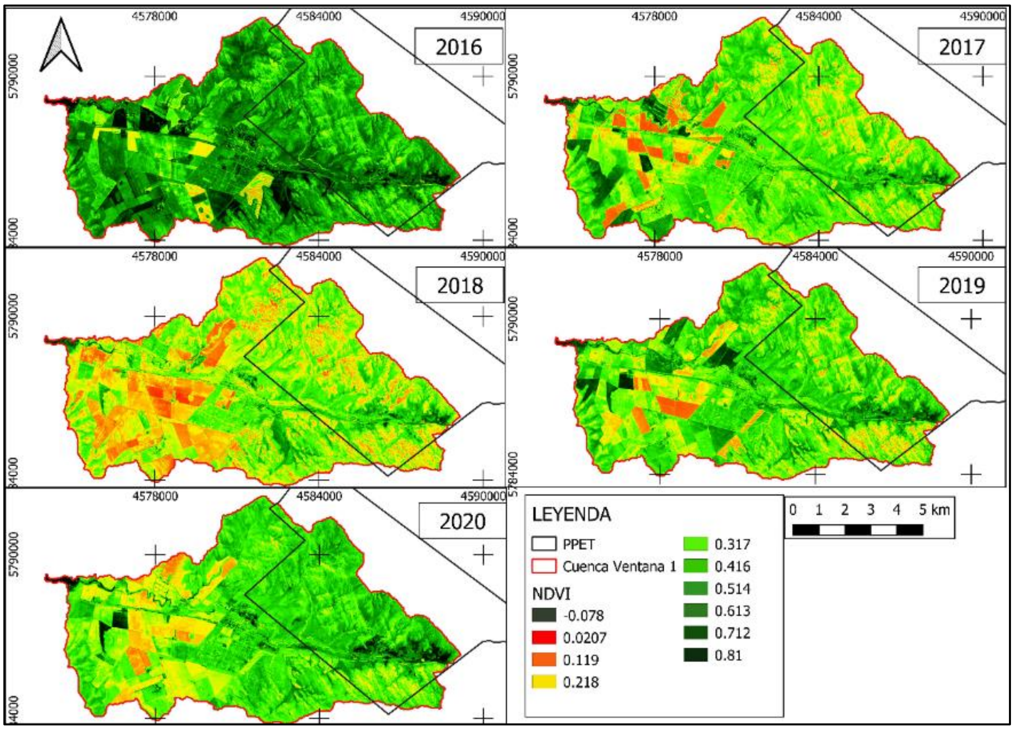

Figure 3. Variation of NDVI values for the Ventana Creek Watershed. Period 2016-2020 (January).

Regarding pastures, those sites that have not been burned show lower values for 2018, due to adverse climatic conditions to produce new biomass, but the opposite is observed in the following years due to better conditions to develop.

The most notorious is what happened with grasslands that have been burned: For the year 2016, higher NDVI values are observed than the other years, probably related to better climatic conditions, especially rainfall (1011mm were recorded in the period October 2015-March 2016), and a corresponding drop almost to 0 due to the fire for the year 2018. For the coming years, a large recovery of values is observed, which are above those sites that have not been affected by the fire.

Finally, the sites occupied by forest stands also have behaviors to highlight. First, there is clearly a drop in values in the year 2018 due to the fire, observed that in the coming years values recover, although it would have to be determined if the site has regenerated forest, if grassland has been established or if the existing trees there have greened up, i.e., the fire has not killed them. Secondly, those sites where no fires have been recorded, both regular NDVI values with variations probably due to climatic reasons, as well as increased values due to tree growth are observed (Figure 4). Finally, sites that have been affected by the 2013 fire have gradually recovered NDVI values due to the new establishment of regeneration on the site. It should be noted that 2016 stands out for higher NDVI values in all coverages, probably due to a benign climate for good plant growth.

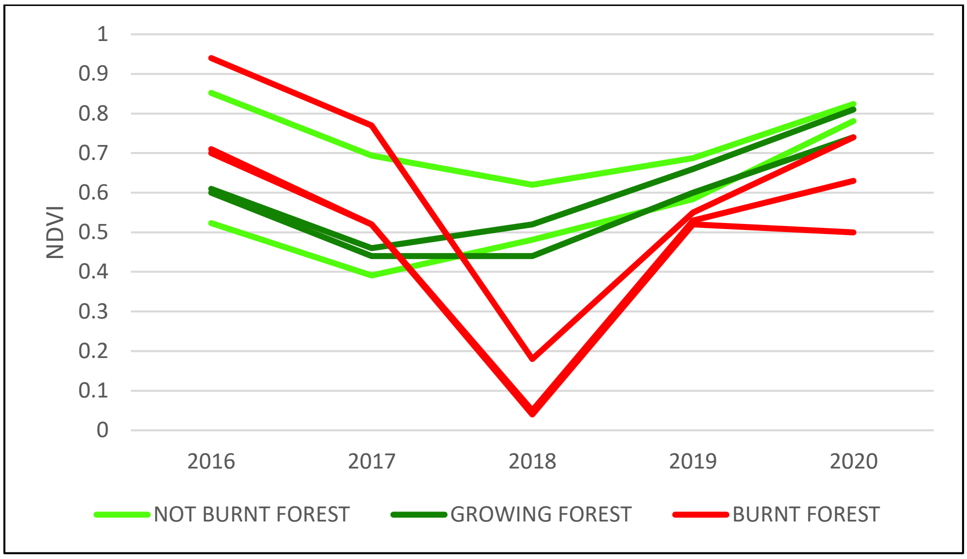

Figure 4. Variation of NDVI values in forests. Lines of the same color represent forest areas that went through the same process (fire, growth, established) at different points. Period 2016-2020.

Variation in forest cover

Figure 5. shows the variation of forest cover (forest) at 4 different times: 2010, 2013 (prior to the first event studied), 2017 (prior to the second event studied) and 2020 (current). The following areas were obtained for each year:.

2010: 162 ha
2013: 170 ha
2017: 141 ha
2020: 170 ha

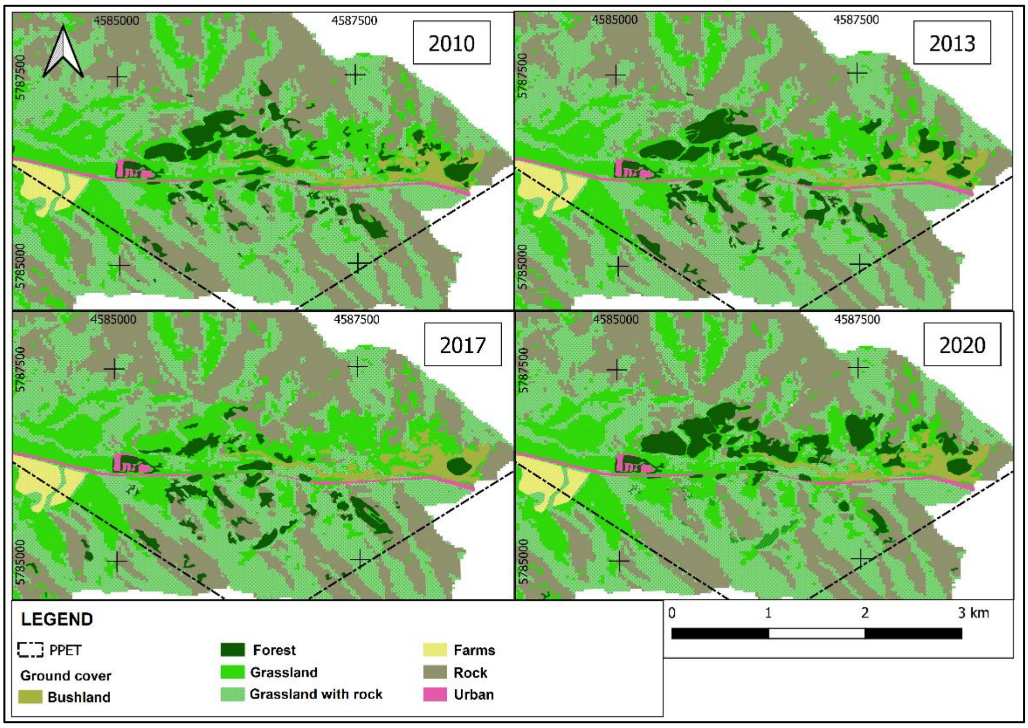

Figure 5. Variation in forest cover.

Although in the aforementioned period there is no great variation in coverage, with a maximum difference of 30 ha between one period and another, Figure 5 shows how this coverage does vary spatially, due to the events that occurred. This spatial variation corresponds to the areas burned in each event. Likewise, a large regeneration is observed between the years 2013 and 2017, taking into account that a large part of the forested area in 2013 was burned (101 ha). However, the decrease in this area was 29 ha.

The variation between the years 2017 and 2020, the period in which the second event studied occurs, should also be noted. The absence of arboreal vegetation in the affected area is clearly observed. Likewise, a great advance over unaffected areas, which are recovering sites burned in the 2013 event.

DISCUSSION

We have studied two events that, although they share a part of the area affected in both fires, present a marked difference in the areas affected as well as the severities recorded.

In terms of forest area, it can be broadly stated that in these cases the fires have been controlling in the sense that the total area did not vary to a great extent. However, it should be taken into account that fire is an important factor for the germination and subsequent establishment of pine trees, which can lead to this species being able to occupy new areas more quickly. It would be important to study the behavior of this species in the future, as long as no new fires are recorded.

The NDVI values recorded for each event, correspond to what was mentioned by Jiménez-Ruano (2016), where he states that after a fire, fire-adapted ecosystems produce an intense profusion of resprouting and germination mechanisms of pre-existing species, which to a large extent determine the pace and intensity of the ecological recovery process. This is defined as "the return of a biological population or community with some aspect of its initial condition after introducing a stressor or disturbance" (Fernández Méndez et al., 2016).

The post-fire response of the applied green indices shows a significant regeneration of vegetation a few months after the fire was extinguished. However, more detailed studies ensure that the consequences on biodiversity are negative and manifest themselves over time, given that exotic species advance over the natural ecosystem, producing modifications in the dynamics of ecosystems and modifying the frequency and intensity of fires (Michalijos, 2018). To this problem must be added the perception of the population, which considers that the mountain ecosystem recovers quickly given that the vegetation regenerates in a few months. According to them, those who are really affected are the owners of tourist ventures who see a decrease in the influx of tourists during the period of vegetation recovery. However, in the present study, it is not possible to determine whether this vegetation corresponds to native species or whether it has allowed the proliferation of exotic species, with consequences for biodiversity, requiring field validation.

With the above mentioned, the multiple factors that affect and play in the functioning and dynamics of the watershed should be taken into account, considering fires as natural processes of the site but that have modified its dynamics due to the introduction of other species to the site. It is a challenge to balance the ecosystem services of watershed protection generated by trees, but which in the long run can have effects that are very difficult to reverse in the natural ecosystem.

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