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Assessing the Evolution in Remotely Sensed Vegetation Index Using Image Processing Techniques

Avaliação da Evolução do Índice de Vegetação de Teledetecção Usando de Técnicas de Processamento de Imagens

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Abstract

Vegetation has a substantial role as an indicator of anthropic effects, specifically in cases where urban planning is required. This is especially the case in the management of coastal cities, where vegetation exerts several effects that heighten the quality of life (alleviation of unpleasant weather conditions, mitigation of erosion, aesthetics, among others). For this reason, there is an increased interest in the development of automated tools for studying the temporal and spatial evolution of the vegetation cover in wide urban areas, with an adequate spatial and temporal resolution.

We present an automated image processing workflow for computing the variation of vegetation cover using any publicly available satellite imagery (ASTER, SPOT, LANDSAT, MODIS, among others) and a set of image processing algorithms specifically developed. The automatic processing methodology was developed to evaluate the spatial and temporal evolution of vegetation cover, including the Normalized Difference Vegetation Index (NDVI), the vegetation cover percentage and the vegetation variation. A prior urban area digitalization is required.

The methodology was applied in Monte Hermoso city, Argentina. The vegetation cover per city block was computed and three transects over the city were outlined to evaluate the changes in NDVI values. This allows the computation of several information products, like NDVI profiles, vegetation variation assessment, and classification of city areas regarding vegetation. The information is available in GIS-readable formats, making it useful as support for urban planning decisions.
Keywords: Image processing techniques, NDVI index, vegetation cover, coastal management

Resumo

A vegetação tem um papel importante como indicador de efeitos antrópicos, especificamente nos casos em que o planejamento urbano é necessário. Este é especialmente o caso na gestão de cidades costeiras, onde a vegetação exerce diversos efeitos que elevam a qualidade de vida (alívio de condições climáticas desagradáveis, mitigação da erosão, estética, entre outras). Por essa razão, há um interesse crescente no desenvolvimento de ferramentas automatizadas para o estudo da evolução temporal e espacial da cobertura vegetal em grandes áreas urbanas, com adequada resolução espacial e temporal. Apresentamos um fluxo de trabalho automatizado de processamento de imagens para calcular a variação da cobertura vegetal usando qualquer imagem de satélite publicamente disponível (ASTER, SPOT, LANDSAT, MODIS, entre outros) e um conjunto de algoritmos de processamento de imagem desenvolvidos especificamente. A metodologia de processamento automático foi desenvolvida para avaliar a evolução espacial e temporal da cobertura vegetal, incluindo o Índice de Vegetação da Diferença Normalizada (NDVI), o percentual de cobertura vegetal e a variação da vegetação. Uma digitalização prévia da área urbana foi necessária. A metodologia foi aplicada na cidade de Monte Hermoso, na Argentina. A cobertura vegetal por quarteirão foi computada e três transectos sobre a cidade foram delineados para avaliar as mudanças nos valores de NDVI. Isso permite o cálculo de vários produtos de informação, como perfis de NDVI, avaliação da variação da vegetação e classificação das áreas da cidade em relação à vegetação. A informação está disponível em formatos legíveis pelo GIS, tornando-a útil como suporte para decisões de planejamento urbano.
Palavras-chave: Técnicas de processamento de imagens, índice NDVI, cobertura vegetal, gestão costeira

1 Introduction

Gathering precise quantitative and qualitative information of biophysical variables is a significant enterprise in environmental, economical and governmental planification and management. Among the most meaningful examples of these information sources is the land use and the land cover. The first one corresponds to human activities and the diverse uses carried out over land. The second one refers to components that cover the earth surface, including biotic and abiotic substances (Prakasam, 2010; Pandian et al., 2014; Ibharim et al., 2015). In particular, vegetation cover has noticeable effects on energy interchange near the surface. This has an influence on air temperature, climate change and climate comfort of city dwellers (Unger et al., 2009; Shashua Bar et al., 2010). Moreover, the vegetation cover percentage is considered a suitable criterion to identify and measure land degradation and desertification in arid and semiarid regions, and to assess anthropic effects as well (Xiao & Moody, 2005; Barati et al., 2011). In general, a dense vegetation cover on unconsolidated slopes is a good indicator of stable and under low stress or hazard potential, except in tropical areas where even unstable areas vegetate quickly.

The importance and nature of vegetation changes in coastal cities is a complex issue for several reasons. Vegetation at or near the shoreline may be considered an obstacle when it obscures the ocean view, since it may decrease the land value. However, natural vegetation is a crucial environmental asset in coastal cities, and should therefore be preserved. The presence of well-developed growth of grass, shrubs, and trees on the backshore of a beach suggests low erosion potential and infrequent salt water intrusion. Mature maritime forests are offer good protections against wind and harsh weather, but the soils in coastal areas are usually deficient in the required nutrients, and are also saline and devoid of freshwater. Many vegetation species are unable to cope with the extreme conditions that these kinds of soils provide, given that the natural porosity determines growing conditions that are rather dry, even if the geographical area is rainy. In spite of this, many species have adapted and strive even in harsh coastal environment. These adaptations include increased thickness in the leaves to protect the plant from dehydration, exposure to the sun and salt spray as well as the ability to delay germination in response to excessive salt spray, dehydration or other environmentally rough conditions. Furthermore, as the distance from the shore increases, the varied adaptations of plants to tolerate coastal conditions decreases (Department of Primary Industries Parks Water and Environment - Tasmania, 2017).

Spatial and temporal distribution of vegetation cover has become a focus of attention in natural areas, urban management planning, microclimate, agriculture, ecology, health, building, urban comfort and people's quality of life (Kawashima et al., 2000; Georgi & Dimitriou, 2010; Bowler et al., 2010; Dadvand et al., 2012). The importance of evaluating vegetation cover with a minimal impact on it has motivated the use of remote sensing techniques (Nageswara Rao et al., 2005; Chouhan and Rao, 2011; Bhandari et al., 2012). These techniques have allowed the development of different indices based on satellite data and have been used in many research projects to estimate vegetation cover (Gilabert et al., 2002; Kallel et al., 2007; Jiang et al., 2008a).

These indices have been useful to estimate parameters such as leaf area, biomass and physiological activities (Baret & Guyot, 1991; Lan, 2009). They are based on red and near infrared reflections that have high correlation with leaf area index and canopy cover (Broge & Leblanc, 2001). However, in sparse vegetated areas, the reflection of soil and sand is much higher than the reflection of vegetation.

Many projects developed specific vegetation indices (Dimoudi & Nikolopoulou, 2003; Jiang et al., 2008b). Barati et al. (2011) compared and evaluated twenty different vegetation cover indices, classifying them into five different categories. These included conventional ratio and differential indices such as the single difference (e.g. DVI), single ratio indices (e.g. SR), normalized difference indices (e.g. NDVI), soil adjusted indices (e.g. SAVI) and triangular indices (e.g. MTVI). The Centre for Renewable Energy Sources (CRES) project identified the effect of vegetation on microclimate. In particular, they addressed the thermal and vegetation effects

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on solar and daylight access. The plant behavior under different environmental conditions considering the interrelationship between vegetation, climate and urban environment was studied, as well as the thermal impact of vegetation and the reduction of air temperature in an urban context (Dimoudi & Nikolopoulou, 2003).

The temporal evolution of these indices is the basis for any feasible analysis of the impact over vegetation of natural phenomena (e.g., understanding and assessing seasonal vegetation changes, gauging the effect of global climate change, etc.) or anthropic intervention (e.g., building proliferation, roads, breakwaters, etc.). However, a proper analysis of the temporal evolution of the vegetation indices poses several methodological difficulties, given that this requires the fusion of information of two or more satellite images taken under different contexts (sun position, weather and radiometric conditions, etc.). The aim of this paper is to study the spatial and temporal variation of vegetation in Monte Hermoso city, Argentina, using specifically designed image processing techniques. The analysis of vegetation cover in Monte Hermoso is essential in the coastal management planning considering that it is a tourist coastal city and the vegetation is disappearing. We developed specialized algorithms for processing satellite imagery, providing automatic and calibrated estimations that allow to evaluate the temporal evolution of NDVI and other vegetation indices. All the information is managed in data formats compatible with most Geographic Information Systems, which allows further studies and the elaboration of coastal management plans.

2 Materials and Methods

2.1 Study Area

One of the most important tourist centers on the Argentine Atlantic coast is the city of Monte Hermoso, located in the Southwest of the Buenos Aires province, (61° 15’*W;* 38° 59’ S). Its 32 km long coast has an E-W orientation, between Punta Sauce in the East and Punta Pehuen Co in the West (Huamantinco Cisneros, 2012) (Figure 1A). The city is characterized by a continuously increasing tourist influx. In 2016, this coastal city was distinguished as the most popular coastal destination in the country (Cámara Argentina de Comercio, 2016). The urban area has an extent of approximately 186 ha with a longitudinal location in accordance with the coastal orientation and an urban plan layout in agreement with the underlying morphology. Some areas have an irregular distribution following the level curves whereas some others have a checkerboard street plan layout. The city is extended mainly from West to East and, to a lesser extent, to the North.

The urban design is enclosed by a 7 km wide dune system with different heights ranging between 8.9 and 16.9 m from West to East, respectively. Prior to urbanization, this area was characterized by the absence of tree species and the presence of a grassland cover. Currently existing tree species (such as pines, eucalyptus, tamarisks, or cypresses) have been introduced as part of the urbanization process (Huamantinco Cisneros, 2012). The Argentine Institute of Statistics and Census (INDEC, from its acronym in Spanish) has estimated the stable population of Monte Hermoso at 6495 as of 2010 (INDEC, 2010). This number increases dramatically during the summer season, when the population reaches more than 60000 (Rojas et al., 2014). The main economic activity is tourism, followed by artisanal fishery.

2.2 Data Collection

From all free satellite imagery available, ASTER images were selected considering special requirements (e.g. weather conditions, temporal frequency, best resolution available) instead LANDSAT or MODIS images. A set of ASTER images were obtained from website (NASA, 2017) and used to extract quantitative and qualitative information through digital image processing (DIP) techniques (Figure 1B). These images have a 15 m spatial resolution and consist of 14 multispectral bands. To identify the vegetation cover, we used four images from different dates from 2013 to 2016. All of them were taken during autumn, spring and summer. Table 1 summarizes the four image specifications.

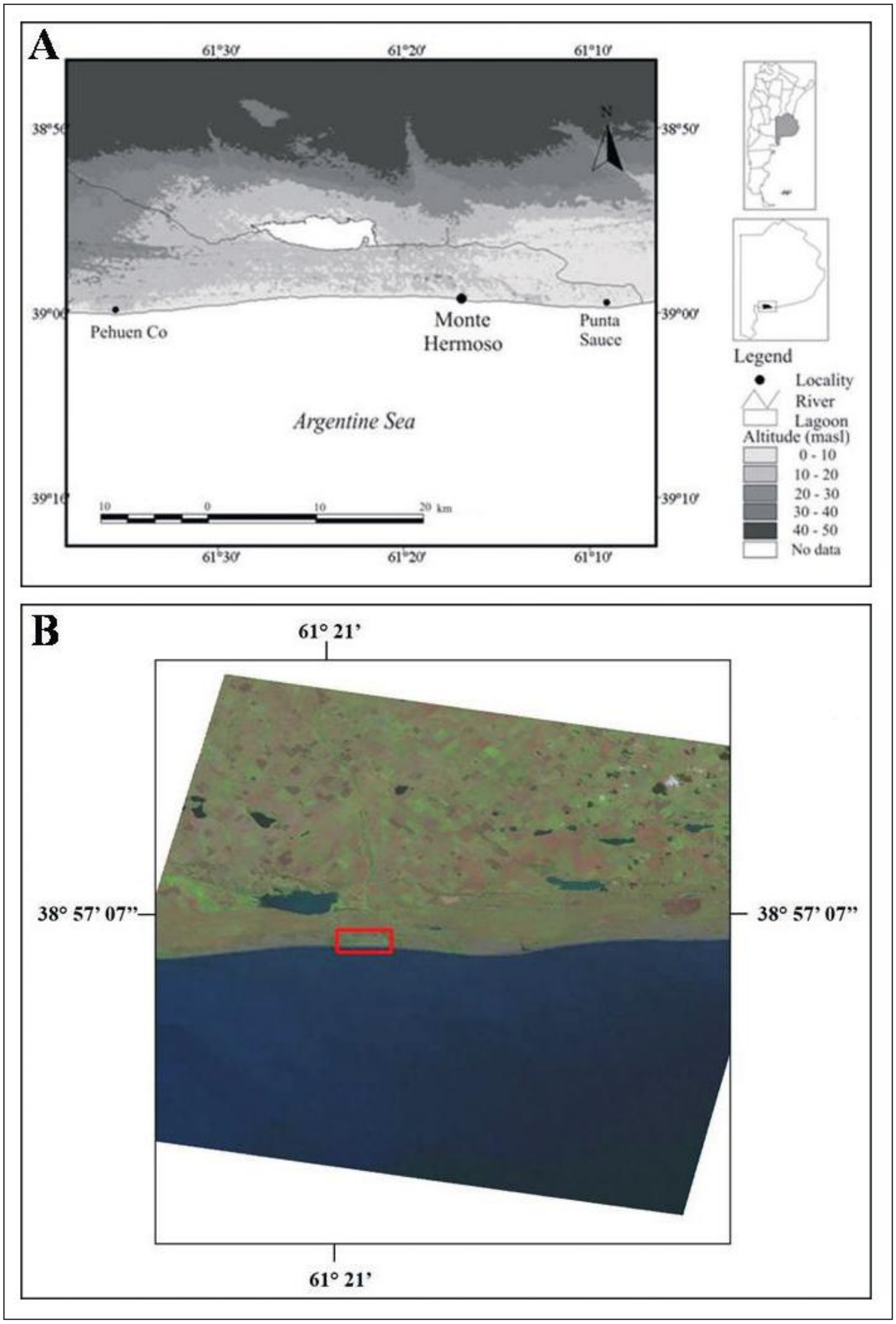

Figure 1 (A) Study zone where the methodology was applied; (B) Aster image composed by the Visible Near Infrared bands (1, 2, 3) corresponding to May 5, 2016, where the study zone (ROI= region of interest) is marked in red.

Table 1 ASTER data description.

Year	Month and day	Season
2013	January 31	Summer
2014	October 31	Spring
2015	December 14	Spring
2016	May 6	Autumn

2.3 Image Processing

An automatic processing methodology was developed. The user intervention was required only at the stage of interpretation of the obtained data. The resulting algorithm was developed using open source tools: Phyton (https://www.python.org) and GDAL (http://www.gdal.org), and consists of three stages: preprocessing, segmentation and classification (Figure 2).

2.4 Preprocessing

In the first stage, the influences of atmospheric effects (i.e., path radiance and water vapor) were corrected in ASTER images. Radiometric and atmospheric correction were performed using the tools of QGIS (Quantum GIS) software. The subsystem (VNIR) with bands 1, 2 and 3 (spectral range from 0.52 to 0.86 µm), was combined to create a false color image (Figure 1B). Then, a region of interest (ROI) enclosed by four control points was selected to avoid unnecessary processing time. Simultaneously, a mask over the ROI was digitalized manually by an expert (Figure 3), covering the areas with major vegetation density. The pixels inside the mask were considered at a further stage. The study zones determined by Huamantinco Cisneros et al. (2016) were used to define the southern boundary of the mask area. The paved and the dirt roads determine the North border. Overall, the mask consists of 500 points and encloses natural and urban areas.

The vegetation cover in urban and natural zones was evaluated using the Normalized Difference Vegetation Index (NDVI). This index takes advantage of the fact that photosynthetic activity absorbs most of the solar energy in the red-green area of the

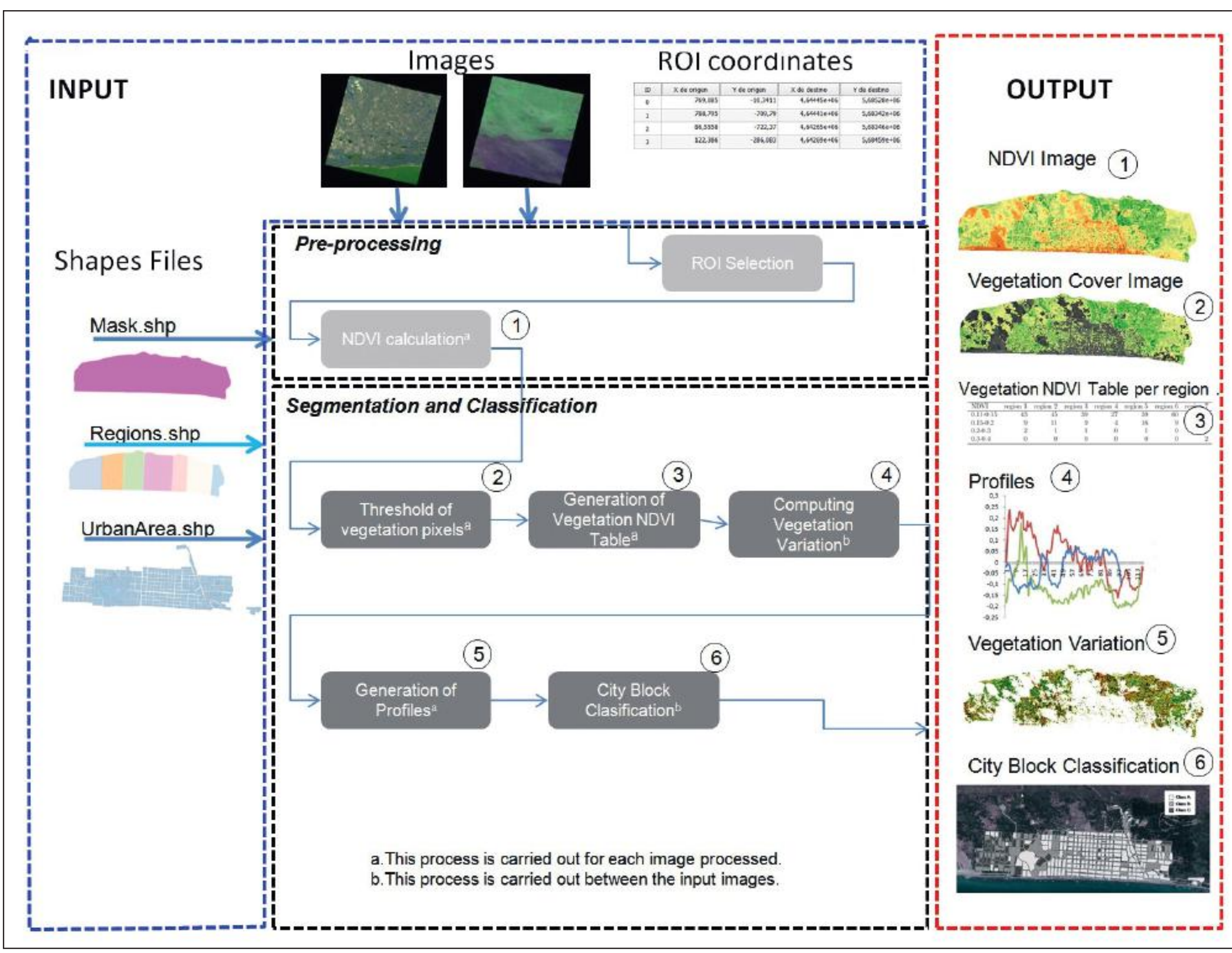

Figure 2 Complete processing pipeline for classification of cover vegetation: preprocessing, segmentation and classification.

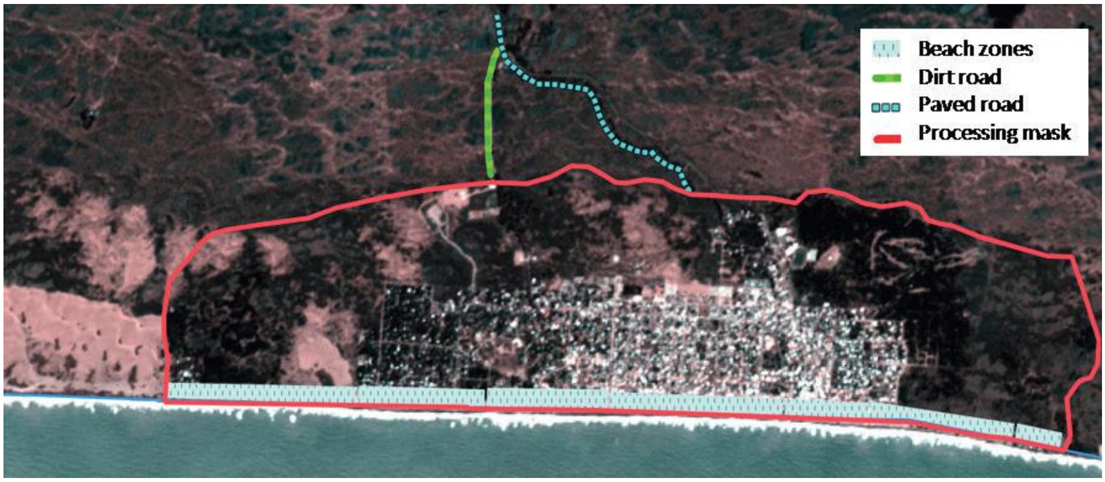

Figure 3 True color Aster image with the manual digitalization of the mask; pixels inside the red region mask were only considered for further image processing and beach zones (in light blue) divide the study area in regions.

radiation spectrum, and re-emits most of the near infrared (NIR) energy. In other words, the more chlorophyll is present, the higher inbalance arises in the visible *vs.* infrared absorbed radiation. For this reason, NDVI is the most commonly used vegetation index, and is highly revealing of the physiological conditions of vegetation, the vegetation distribution over geographical areas, and the vegetation dynamics (Eidenshink, 1992; Marsh et al., 1992; Lyon et al., 1998). NDVI can be defined as the normalized difference between the NIR re-emited energy and the visible re-emited energy:

$$NDVI= \frac{(NIR-Vis)}{(NIR+Vis)}$$

where and represent the near-infrared and visible reflectances, respectively. In practice, for most of the spaceborn sensors including ASTER and LANDSAT, the NDVI is approximated using only two spectral bands (bands 2 and 3 in MODIS, and bands 3 and 4 in LANDSAT). Also, more sophisticated vegetation indices were proposed that take into account green and blue radiation (for instance, the Enhanced Vegetation Index) (Jiang et al., 2008b; Rocha & Shaver, 2009). NDVI ranges are between -1 and 1. In general, pointwise values higher than 0.7 represent healthy, thick and wet vegetation like rainforests; between 0.3 and 0.6 represent shrub and grasslands; between -0.2 and 0.2 represent barren or urban areas, and values below -0.4 represent water. With pixels covering wide areas (e.g, 900 m^2 as with LANDSAT or ASTER imagery) and high spacial variance (as in urban areas) these values tend to be much lower due to the *mixed pixel* effect.

2.5 Segmentation and Classification

Initially, the study area was divided and manually digitalized into seven regions, following the beach zone criterion (land use) proposed by Huamantinco Cisneros et al. (2016). The urban area was manually digitalized through area recognition and the use of specific GPS waypoints. Information in vector format (polygon layer) of all the city blocks was generated, integrated and stored into a Geographic Information System (GIS). Each city block was extracted from the urban area layer, obtaining a mask (Figure 4). The image processing algorithm took each digitalized region as an individual mask, and for each, the NDVI pixel values were evaluated. Three different vegetation cover classes were defined according to the amount of green spaces present in each city block (Table 2). Furthermore, the software evaluated NDVI values on transects. Longitudinal transects parallel to the coast were outlined to evaluate the spatial variations of the NDVI values. The transects were outlined in three different ways: $Tr_{c(i)}$, $Tr_{m(i)}$ and $Tr_{r(i)}$ where c indicates coast line, m middle line and r remote line of the i-th region. Both the NDVI evaluation and the classification of vegetation percentage are unsupervised, requiring only the vector masks and the pre-processed satellite image as stated in the previous section. Therefore, the whole processing pipeline can be easily repeated over sets of images.

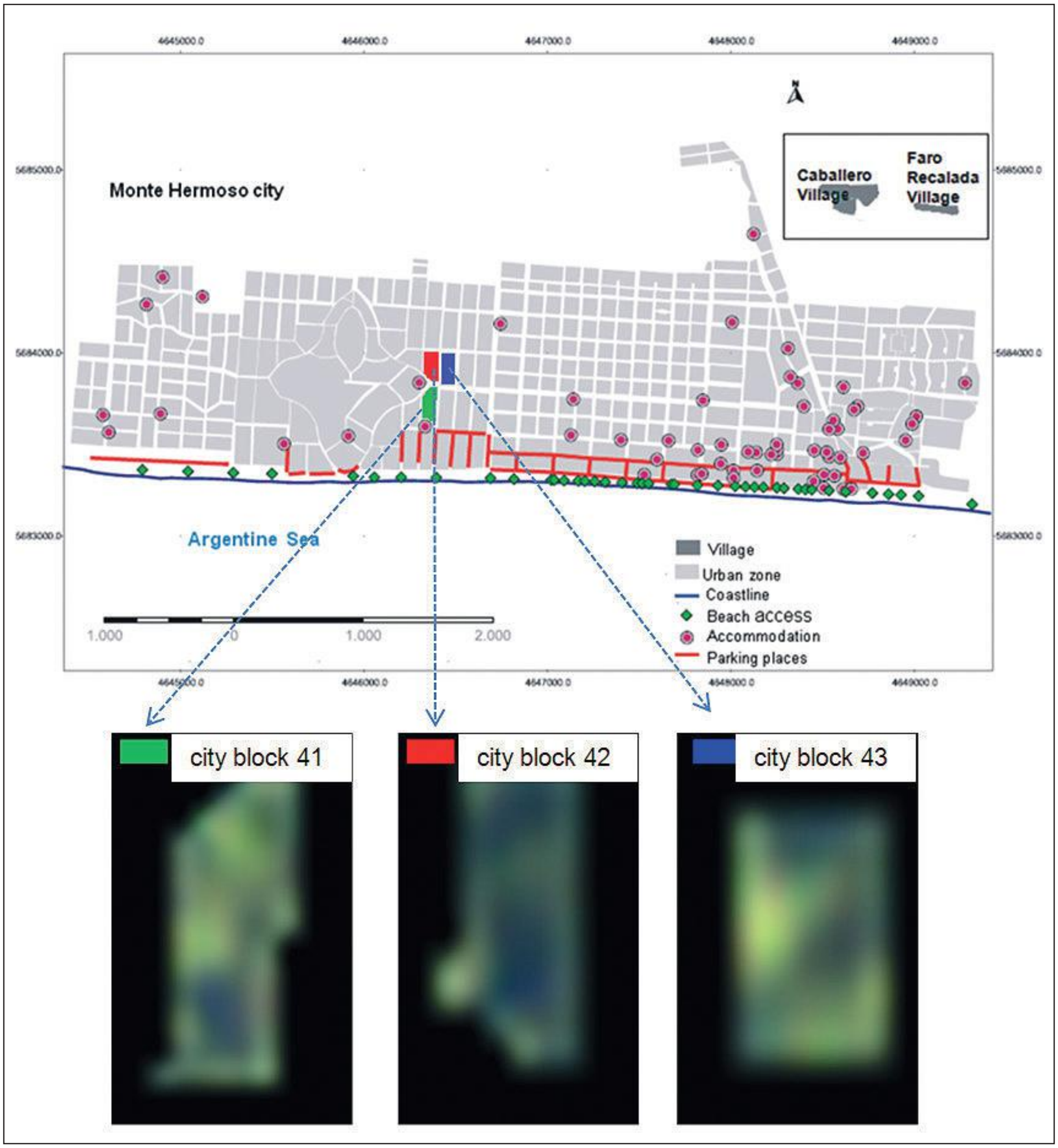

Figure 4 Extraction of city block masks from urban information.

Vegetation density	Coverage (in %)	Class
Scarce	<60	A
Medium	60-80	B
High	>80	C

Table 2 Vegetation cover classes in each city block.

3. Results and Discussion
3.1 Estimating NDVI and vegetation cover

The first processed information product of the software is the pseudocolor cropped image; the input parameters are ASTER images, ROI coordinates and a mask shape file. This mask image was used to analyze a region delimited by a polygon (Figure 5). As a second product, the software generates a pseudocolor NDVI image. This image has a ranges between a minimum and maximum value extracted from NDVI values (Figure 6). The product also provides a vegetation cover image (Figure 7). All these software features allows potential users to process the same region along different periods of time.

As an example, four NDVI (Figure 6) and vegetation cover images (Figure 7) from different years are presented. The NDVI values ranged from

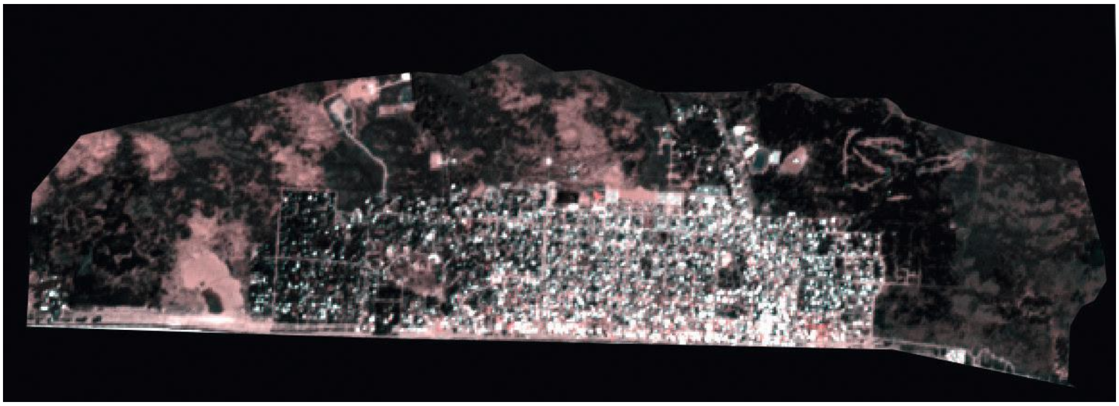

Figure 5 Cropped image produced by the software considering both the region mask and the image as input parameters.

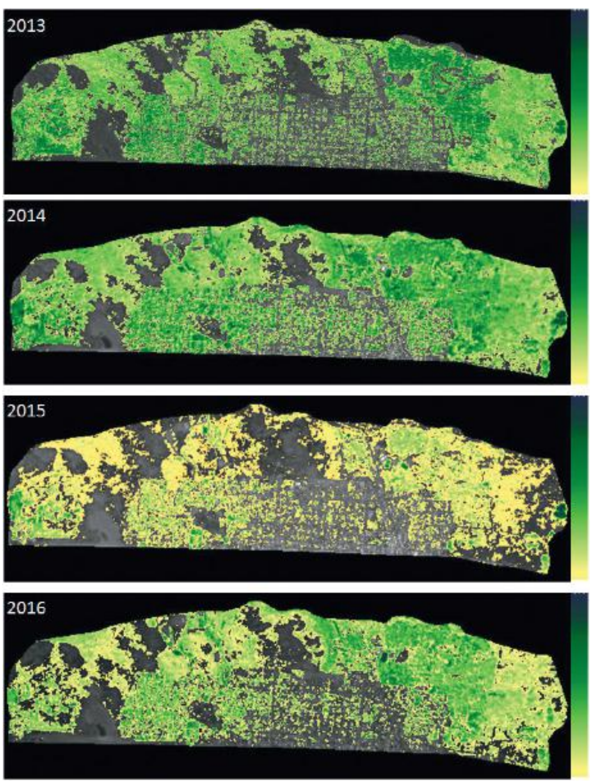

Figure 6 NDVI product images from 2013 to 2016. NDVI values range from -0.3 to 0.5. Values less than or equal to 0.1 represent the urban area, roads, and sand. Values greater than 0.1 correspond to the vegetation cover.

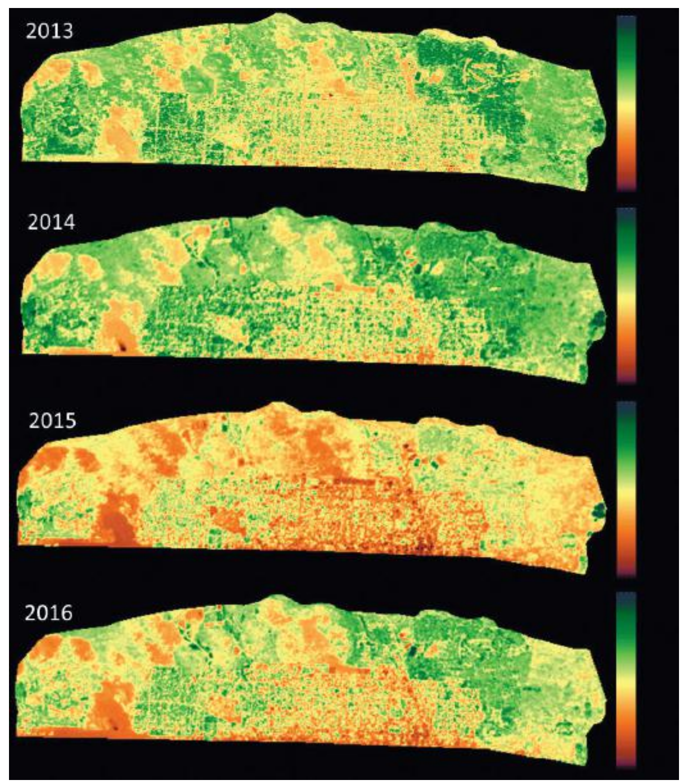

Figure 7 Vegetation cover image products from 2013 to 2016. Healthy and unhealthy vegetation types are shown in dark green and yellow color palette, respectively.

-0.3 to 0.5. Values less than or equal to 0.1 represent urban area, roads, and sand, whereas values greater than 0.1 correspond to vegetation cover. In 2013, NDVI negative values were observed both in dune areas and inside urban areas (vegetation mixed with buildings). Northeastern and southwestern city sectors exhibit the larger NDVI values. A major vegetation development was identified at the eastern and western city boundaries in 2014. Moreover, the highest NDVI values were seen at both city entrances and the camping/recreational complex. Sparse vegetation activity was observed in city center areas, at the northern urban boundary and in some spaces near the eastern entrance. A low NDVI value was observed to the west of the city, associated with a mobile dune area.

In 2015, there was a remarkable decrease of NDVI values with respect to the previous year. Negative NDVI values were higher than in 2014 at the mobile dune areas to the north and west of Monte Hermoso, specially in the coastal road that connects the city with the camping/recreational complex mentioned. Meteorological data previous to the image dates registered temperatures between 25 and 31.6 °C without precipitations, which could explain high temperatures and absence of water could be the reasons for a lower vegetation indices.

In 2016, green zones to the east, northeast and west of the study area were recovered. Previous meteorological conditions were characterized by a mean temperature of 8.8 °C, a mean relative humidity of 85 % and precipitations of 0.8 mm.

The last condition provided a better context for the vegetation health recovery. Negative NDVI values remained constant in the urban areas (seafront and east entrance of the city) and to the west of the study area (mobile dune). According to the vegetation cover images, years 2013 and 2014 showed an increase in the vegetative activity in spaces surrounding the city. In 2014, positive NDVI values were identified, with a major intensity inside the blocks. Monte Hermoso seafront, densely urbanized and very close to the beach, did not present vegetative activity (negative NDVI values).

In 2015, a remarkable decline of precipitations along with the hot summer period could be the reason for the observed NDVI value decrease. Low values of NDVI were identified in the densely urbanized area (e.g. buildings close to the football field). In 2016, a slow recovery of vegetative activity was noticed to the east and southwest of Monte Hermoso.

3.2 Managing Split Regions

The software allows to subdivide the study area into smaller regions, which is especially useful when the regions have distinctive features. To accomplish this, it is necessary to add shape files for the regions to be processed (Figure 8A). Then, the whole processing pipeline can be applied inside the separate shape files and deliver results for the vegetation cover in each region. It also provides information about the profiles parallel to the coastline (Figure 8B). As output, we obtained information of NDVI including vegetation cover and profiles images.

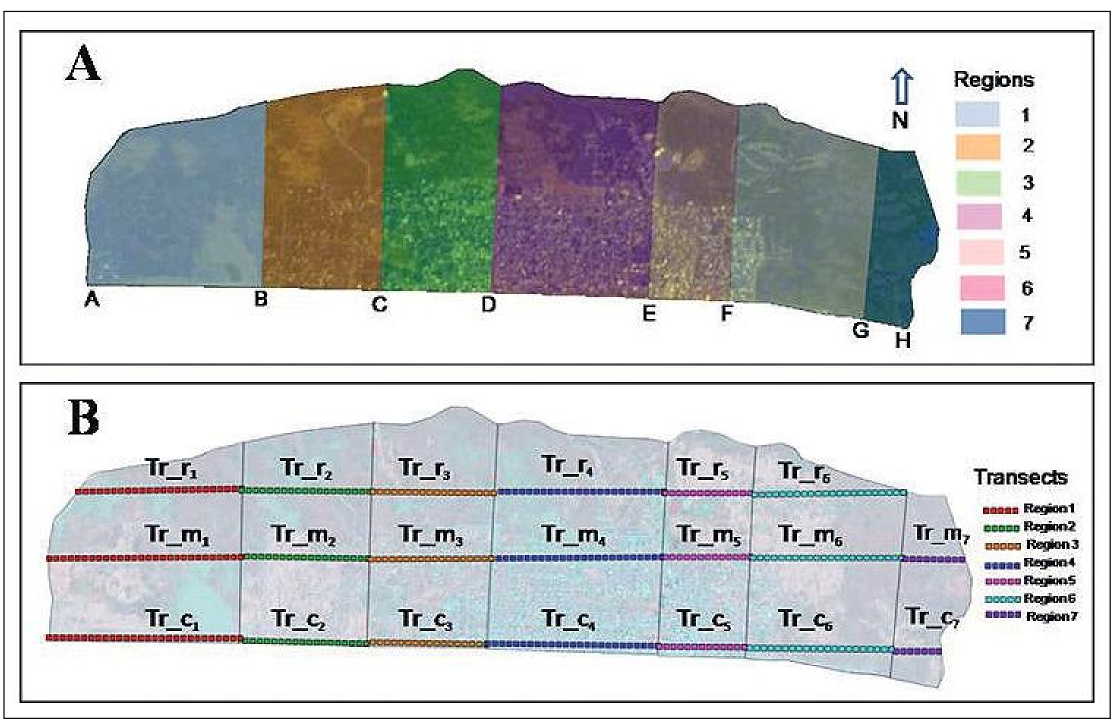

Figure 8 (A) Delimitation of the regions over the mask (A to H); (B) Transect locations per region, parallel to the coastline where $Tr_{e(i)}$, $Tr_{m(i)}$ and $Tr_{r(i)}$ indicate remote, intermediate and coastal transects, respectively and the subscript represents i-th region.

The region shape files were carefully chosen and characterized as follows:

Region 1: Limited by point A (recreational/ camping complex) and point B (western boundary of the city). Natural spaces such a (nonoriginal) vegetation, mobile dunes and vegetated dune areas are predominant. At the southwestern boundary of this region, there is a recreational/camping complex with a few buildings (lodging and tourism spaces for visitors). This region is near a Paleontologic and Natural Provincial Reserve.

Region 2: Located between points B and C. It corresponds to the southwestern extreme boundaries of Monte Hermoso. This region presents a mixed vegetation cover, mobile and vegetated dunes, a dense urban woodland, houses and streets areas. One of the entrances to the coastal city is also in this region.

Region 3: Defined between C points and D. The southern part of this region corresponds to an urban area with houses and streets. The urban woodland is scattered and smaller than in region 2. The northern part is characterized by introduced vegetation, natural vegetation and mobile and vegetated dune areas.

Region 4: Located between D points and E. This region is mostly urban area (dense concentration of buildings). The urban woodland is smaller than in other areas. To the northeast, there is an extensive mobile dune area mixed with a vegetated dune one. The main entrance to the city is located in this region.

Region 5: It extends from points E to F. This region is mostly of urbanized occupancy. It is one of the most transformed areas due to the building construction related to the urban growth tendency (to the east of Monte Hermoso). There is a non urbanized area integrated by a forested area (north of the region).

Region 6: Limited by points F and G. It contains a minor urban area situated in the eastern boundary of Monte Hermoso. It is also considered as an area for future urban development. There are two small villages (Caballero and Faro Recalada) along the coast. Both of them belong to Monte Hermoso urban area. This region is mainly occupied by a forested area and vegetated dune areas.

Region 7: Defined between points G and H. A great vegetated dune area is identified along with some small mobile dune areas.

In addition, a region-wise analysis of vegetation cover changes was carried out. Regions 1, 2, 6 and 7 presented a high vegetation cover, over 61 %. The highest (90 %) and the lowest (37 %) vegetation cover percentages were represented by regions 7 and 4, respectively. In general, the vegetation cover in 2014 grew up over 62 %. Regions 2, 6 and 7 presented high thickness vegetation cover percentages. In 2015, all regions showed low percentages of vegetation cover, under (69 %). In this case, region 6 presented the highest percentage (69 %), and the lowest (31 %) corresponded to region 4. In 2016, the study zone could recover vegetation (80 %) compared with the previous year. Regions 6 and 4 presented the highest (85 %) and lowest (44 %) vegetation cover percentages, respectively. These changes in vegetation cover percentage are shown in Table 3.

Year	NDVI	R1 (%)	R2 (%)	R3 (%)	R4 (%)	R5 (%)	R6 (%)	R7 (%)
2013	0.11-0.15	34	35	39	29	25	38	59
	0.15-0.2	22	21	16	8	19	30	27
	0.2-0.3	6	8	1	0	12	14	3
	0.3-0.4	0	0	0	0	0	0	1
	Total (%)	62	60	56	37	56	82	90
2014	0.11-0.15	40	43	47	35	29	36	69
	0.15-0.2	19	29	22	19	39	50	18
	0.2-0.3	4	5	4	2	6	6	4
	0.3-0.4	0	0	0	0	1	0	3
	Total (%)	63	77	77	56	75	92	94
2015	0.11-0.15	43	45	39	27	39	60	35
	0.15-0.2	9	11	9	4	16	9	6
	0.2-0.3	2	1	1	0	1	0	2
	0.3-0.4	0	0	0	0	0	0	2
	Total (%)	54	57	49	31	56	69	45
2016	0.11-0.15	41	46	38	29	28	48	71
	0.15-0.2	7	20	19	14	34	35	11
	0.2-0.3	0	1	1	1	3	2	1
	0.3-0.4	0	0	0	0	0	0	0
	Total (%)	**48**	**67**	**58**	**44**	**65**	**85**	**83**

Table 3 Percentage of NDVI values per region in years 2013-2016. NDVI values above 0.4 are negligible.

Figure 9 shows the NDVI profiles along the transects as located in Figure 8 during 2015. The profiles in region 1 show a large incidence of NDVI negative values, especially in the coastal and remote transects. The first is in agreement with the dominant presence of sand along almost the whole transect. The lowest value was close to -0.25. Higher NDVI values in this transect (that rise up to 0.18) is associated to the coastal vegetation over dunes. Most of highest vegetation NDVI values were observed on the middle transect. These values are related to pine forest areas in the west of the region. The other low values of this transect were associated with dune presence. The farthest transect had also low NDVI values (due to dune predominance) but evidenced some vegetation influence (specially related to pines and other introduced trees).

In the profiles of region 2, the coastal and middle transects show a vegetation and non vegetation alternation in open air spaces (dunes, streets and buildings), according to the residential area development to the western boundary of the city. On the coastal transect, positive NDVI values are associated to the presence of tamarisks over the dune line. The remote transect has negative NDVI values due to the presence of dunes. In region 3, there is a remarkable fluctuation between vegetated and non vegetated places in all the transects. The highest NDVI values depended on the urban woodland, whereas the lowest ones referred to sand/dune or building areas.

Intermediate and coastal transects in region 4 exhibit a predominance of low NDVI values corresponding to high density urban area (building and pa-

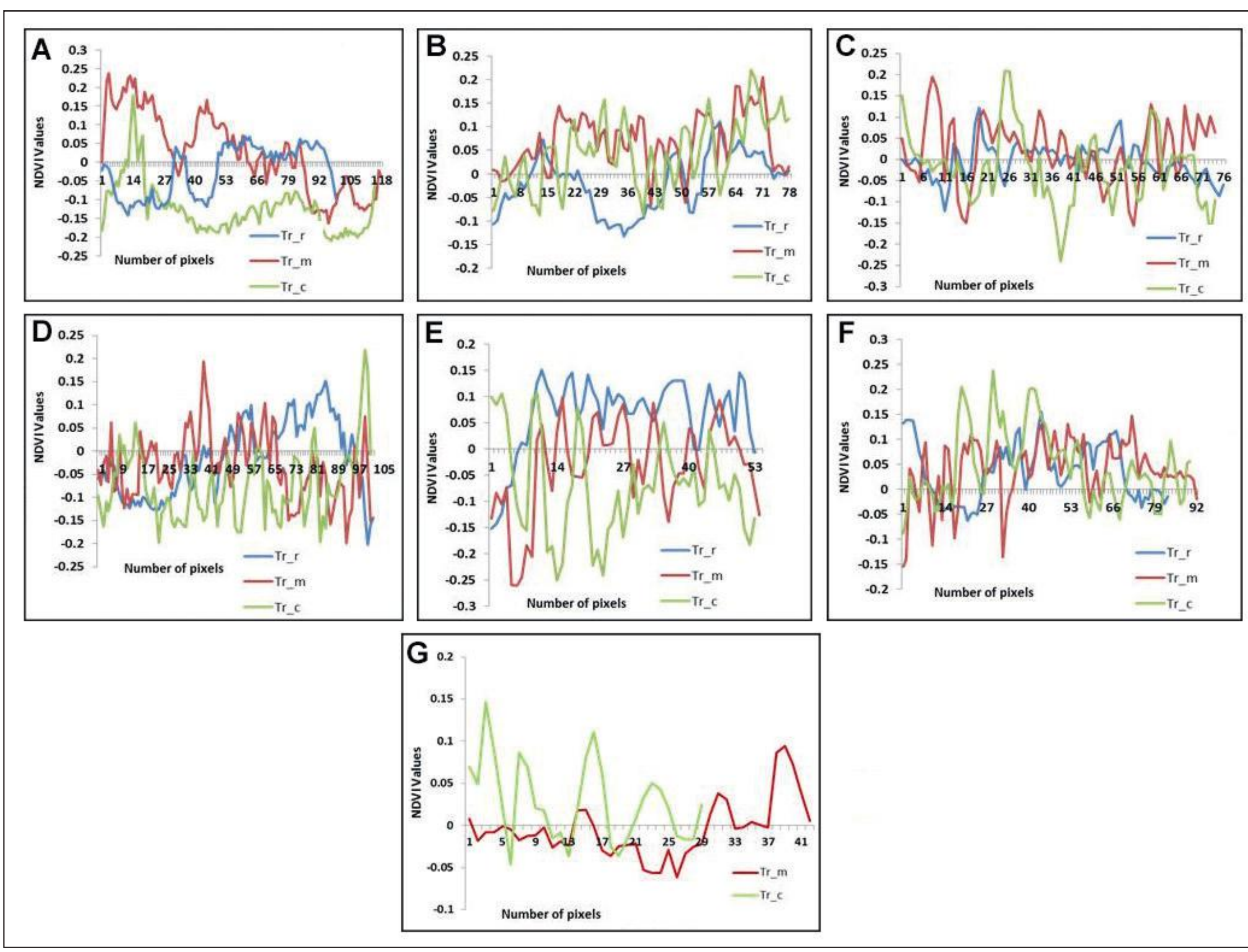

Figure 9 Region-wise NDVI profiles in 2015. Each profile represent the transects values per region, parallel to the coastline where Tr_r, Tr_m and Tr_c indicate remote, intermediate and coastal transects, respectively. (A) Region 1; (B) Region 2; (C) Region 3; (D) Region 4; (E) Region 5; (F) Region 6 and (G) Region 7.

ved streets). The highest NDVI values represent the presence of urban woodland and native vegetation, notoriously in the remote transect. In region 5, the high urban density with scarce green spaces is noticed on the coastal transect. Only the intermediate transect shows an alternation between non vegetated (buildings, streets, etc.) and green spaces. On the remote transect, comparatively higher vegetation activity was predominant. The three transects in region 6 exhibit relatively high NDVI indices, in spite of the presence of sand (beach) and urban structures. Finally, in region 7 the coastal transect has positive NDVI values according to grassy, arbustive and introduced vegetation. The other transects show lower a NDVI, due to the predominance of dunes.

3.3 Estimating Vegetation Cover Variation

Another salient feature of our software is the computation of vegetation cover temporal variation. Taking two images of the same location at different dates, after all the corrections, vegetation variations can be assessed (see Fig. 10). These image products are useful to understand the temporal evolution of different phenomena caused by natural or anthropic activities.

For the period 2013-2014, the vegetation areas without variation were associated with the wooded spaces located at northeastern, western and eastern boundaries of Monte Hermoso and remained constant at 7 %. Main changes were identified in a high percentage (13 %) of the study area, related to an increase of vegetative activity in 2014. The non vegetation cover was coincident with the urban and dune areas. During 2014-2015, the regions underwent a notable change in healthy vegetation; however, only 6 % changed and 3 % did not experiment changes. Little spaces without variation were identified in the wooded area close to the recreational complex (western sector) and to the eastern city boundary. The non vegetation area showed a minor decrease compared to the previous period.

For the period 2015-2016, vegetation recovered spaces, both in the urban and the surrounding areas. The vegetation cover varied to 30 %, whereas 16 % remained constant. Non vegetation spaces occupied an important part of the study area. Spaces

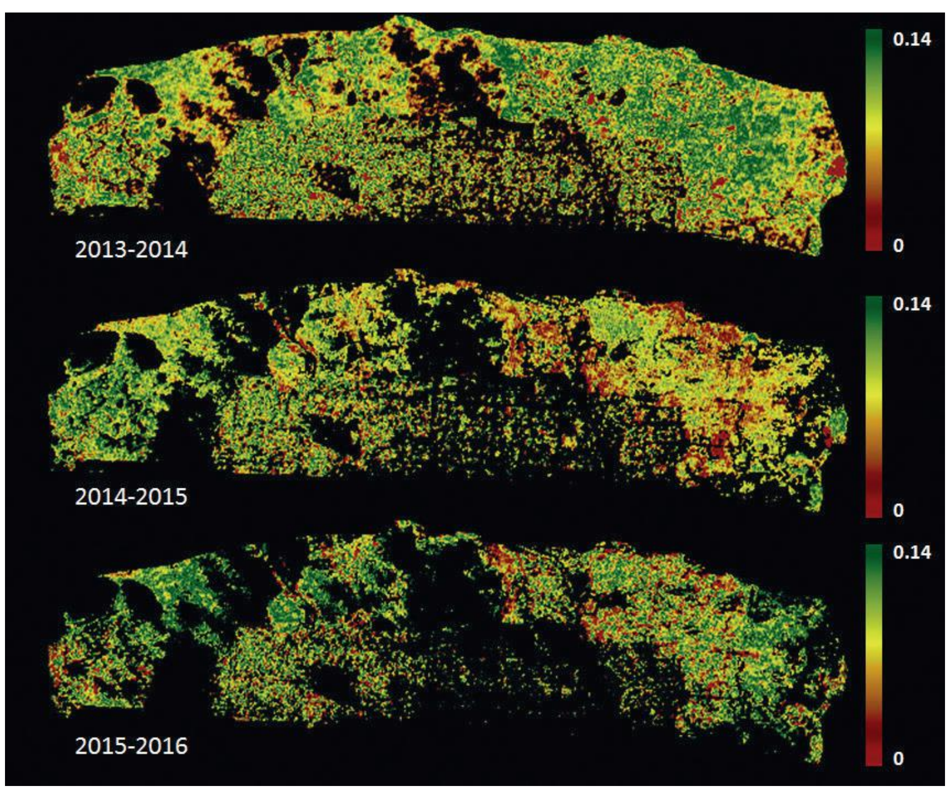

Figure 10 Variation in vegetation cover from 2013 to 2016.

without changes in vegetation cover were scattered and located in Monte Hermoso rural area to the north and northeast. These changes are shown in Table 4.

Year	No changes (%)	With changes (%)
2013-2014	7	13
2014-2015	3	6
2015-2016	16	30

Table 4 Percentage of variation of vegetation cover during the years 2013-2016.

3.4 Including the Urban Zone

The software enabled to add a shape file of an urban city as a new feature of the tool. With this information, it was possible to extract each block of the city. After block extraction, NDVI vegetation values were analyzed and categorized into different classes. This process produced an image with the city block classification (Figure 11).

An example of vegetation cover per city block for 2016 was analyzed. The blocks were categorized into three classes, A, B and C, according to the amount of vegetation in each city block. A great area of Monte Hermoso presented a low percentage of vegetation (Regions 3, 4, 5 and 6) and were categorized as class A. Regions 2 and 3 were categorized as class B, with a medium percentage of vegetation. Scarce vegetation was identified in regions 4, 5 and 6, categorized as class C. Overall, class A corresponded to the east of Monte Hermoso urban area, class B to regions 3, 4, 5 and 6, and class C to regions 1 and 2.

4. Conclusions

A software to analyze vegetation cover is presented in this paper. The tool allows to analyze specific regions using shape files that can either represent a region of interest which might be cropped from a larger image or divide the ROI into smaller regions with distinctive features for comparative analysis. In addition, the tool enables to compute the temporal variation through images for different periods. Finally, an urban area shape can be used to analyze the vegetation percentage per city block considering a low scale.

Shape file information is gathered using *in situ*, geographic information, historical data and scientific studies.

The analysis of NDVI, vegetation cover, vegetation variation and city block maps allows to recognize the state of vegetation. This information can be considered to make suitable improvements and

Figure 11 Automatic classification of vegetation cover per city block. Low, medium and high vegetation is classified in classes A, B and C, respectively.

planning actions in the selected area. This information is also a valuable indicator of environmental changes (i.e. the state of soil degradation and the beginning of erosive processes, among others). The software results become a useful tool for decision makers in order to mitigate the negative effects of *in situ* monitoring and protect the natural environment.

The algorithm developed is very simple and can be set up in a short time. The software was made integrally with open source programs which are readily accessible to any interested party and can be applied to different multispectral images such as SPOT, LANDSAT, ASTER, among others. These facts make the system adequately suitable for massive use, even in low budget research projects or for authorities requiring long term monitoring vegetation cover. Eventually, the presented methodology can be easily adapted to other contexts and situations.

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