A Computational Analysis of Multi-temporal Vegetation Changes Using the Fractal Dimension Spectrum

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Abstract

We present a methodological work for testing and applying the use of both Fractal Spectrum (FS) and Fractal Dimension (FD) to discriminate and quantify, respectively, cover and structure changes along time in a relic *Abies pinsapo* Boiss. (Pinaceae) forest located at Andalusia (southwestern Mediterranean Basin). To achieve this, plots at different elevation were selected from Orto-rectified aerial photographs of the same locations taken at different dates (from 1957, 1991 and 2001). The selected images were analyzed using *HarFA* software (http://www.fch.vutbr.cz/lectures/imagesci/) in the whole range of thresholding conditions, which allows us to use the Fractal Spectrum (FS) as a criterion for forest cover delimitation and FD characterization. In order to test the accuracy of the method, image thresholding was also determined by mean of a conventional supervised classification of the aerial photographs using *ImageJ* analysis software (http://rsbweb.nih.gov/ij/). The obtained results showed FS analysis might improve the criterion of visual delimitation of forest cover in landscape digital images and, thus an optimal FD characterization. Finally, the obtained FD provided an adequate parameter for detecting the increase in forest cover and vegetation structure diversity in image time analysis series.

1. Introduction

Fractal Dimension (FD) [1] is a useful tool to quantify the inherent irregularity of nature. Fractals are self-similar and infinitely detailed, and the related FD is an index of its morphometric variability and complexity; moreover fractal analysis has been applied to a variety of natural objects [2] and the FD may be obtained even if the object is not a fractal. Thus, among the different methods of FD calculation, the box-counting method is the most appropriate in landscape structural FD estimation because it can be apply to fractal patterns with or without self-similarity.

Potential applications of fractal geometry are not limited to quantifying natural lines and surfaces. Fractal geometry may produce new methods for estimating stand density, predicting forest succession, and describing the form of trees. It is shown that the fractal dimension of tree crowns is a good indicator of various tree and site features such as species tolerance, crown class, and site quality [3]. The aim of our work is to analyse the possible use of Fractal spectrum (FS) in image classification and FD as indicator of stand complexity in Orto-rectified aerial photographs from 1957, 1991 and 2001of relic *Abies pinsapo* Boiss. (Pinaceae) forest from Andalusia in the southwestern Mediterranean Basin.

2. Material and Methods

Digital panchromatic aerial photographs from 1957, 1991 and 2001 were used in order to analyse changes in forest coverage and structure in the last 50 years. ArcView GIS 3.2 (ESRI) was used for selecting, scaling and geographic coordinate determination of plots (six plots of 17.9 ha - 550 m × 325 m - from each image). A digital map scale 1:10000 was simultaneously used to confirm the correct selection of the plot and to determine the mean elevation in metres at sea level (thereafter m a.s.l.).

FS and FD of the digitalized images were obtained using the fractal functions implemented in *HarFA 5.1* software (http://www.fch.vutbr.cz/lectures/imagesci/). A deep computational fractal analysis of images may be easily achieved using *HarFA*, because it includes three categories of the necessary boxes for the box-counting method: N_W, which contains only the white background; N_B, which covers only the black segmented object; N_{BW}, which covers the border of the black object (e.g., those boxes which contains at least part of the black object). According to this counting mechanism it obtains not one but three FDs (FD_W, FD_B, FD_{BW}). Another two FDs (FD_{B+BW}, FD_{W+BW}) can also be computer from N_{B+BW} (the sum of N_B and N_{BW}) and N_{W+BW} (the sum of N_W and N_{BW}). The FS in the whole range of thresholding conditions, also implemented in *HarFA*, was applied to the selected images in order to test the FS as a criterion for thresholding. To confirm this, a conventional image analysis of the plots was carried out by independent observers (experts in the study area and vegetation type) using the computerized-assisted image analysis software *ImageJ* (http://rsbweb.nih.gov/ij/), where the pixel intensity range and the fraction area of *Abies pinsapo* forest was obtained avoiding shadowy zones corresponding to rocks and others topographical irregularities. In addition, the pixel intensity value obtained after interpolation in the FS graph was also used as the conventional maximum threshold delimitation at each image to confirm that FS graphical interpolation is an adequate approach for thresholding and FD relationship (*Figure 1*); to obtain an appropriate FD parameterization, the box-size range was selected after a single slope analysis.

The pixel intensity obtained using both approaches (conventional and FS thresholding) was correlated by linear regression; a statistical significance was tested for $p < 0.01$ [4]. In addition, one-way ANOVA was applied to test FD differences in the time series [5].

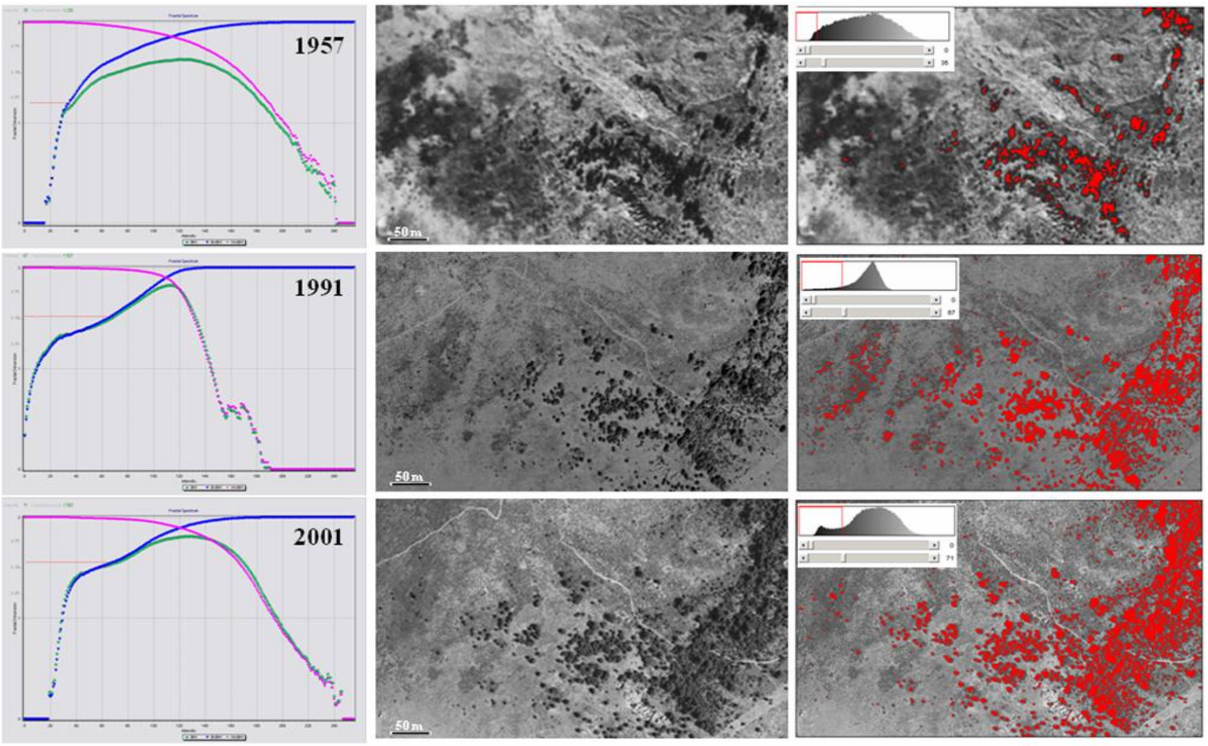

Figure 1 FS (left column) of the selected aerial images (middle colum) at different dates. The selected FD (red horizontal line at left column) was appropriated since it corresponds to an adequate -independently selected- forest covering threshold (right column).

3. Results and Discussion

3.1. Conventional and FS thresholding relationship

Figure 1 shows that the more adequate FD for each image corresponds to the inflexion point of the FS curve related to FD_{B+BW}, because the interpolated pixel intensity value may be used as an appropriate thresholding value for forest covering. Under this value, the pixel range includes the most darkness values (only a mosaic from black and white spots was obtained) and, thus, FD_{B+BW} is too small. Over the selected interpolation point, the range of pixel intensities included is too large, and the forest patches will disappear by overlapping, where the FD_{B+BW} reached a maximum. This visual transition is well noticeable when FS is running in *HarFA*. The critical inflexion point may be also easily detected because just over this point is when the FD_{B+BW} (blue line in *Figure 1*) value start to be different to the FD_{BW} value (green line in *Figure 1*), the functional meaning corresponding to the limit of the forest cover; so, the suitable criterion to determine both the FD and the corresponding pixel range is the first FD_{B+BW} value higher than FD_{BW} value. *Figure 2* shows the linear regression between the values obtained from conventional (visual) and FS thresholding approaches ($p < 0.01$, $R^2 = 0.79$, $n = 18$). Thus, we can assume that the FD_{B+BW} at this threshold is a representative parameter of the forest stand complexity.

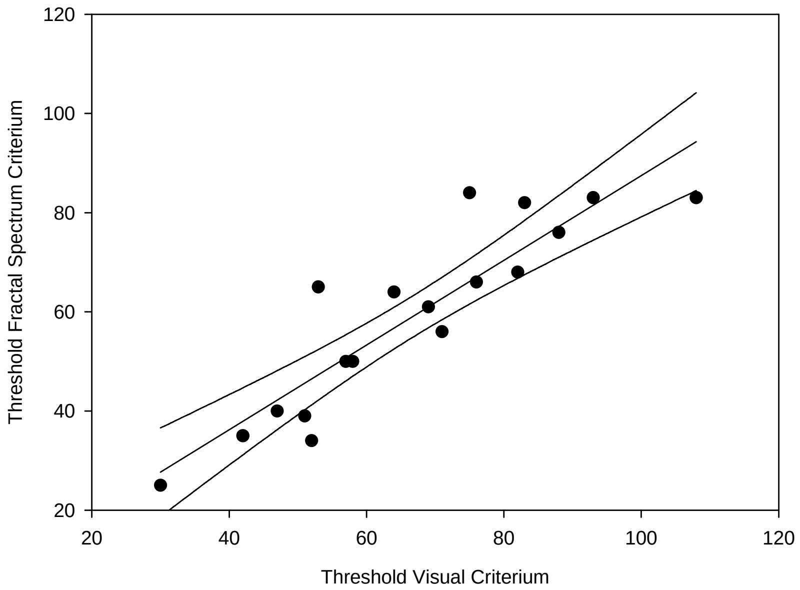

Figure 2 Linear regression performed between the threshold obtained from visual and FS delimitations ($p < 0.01$, $R^2 = 0.79$, $n = 18$).

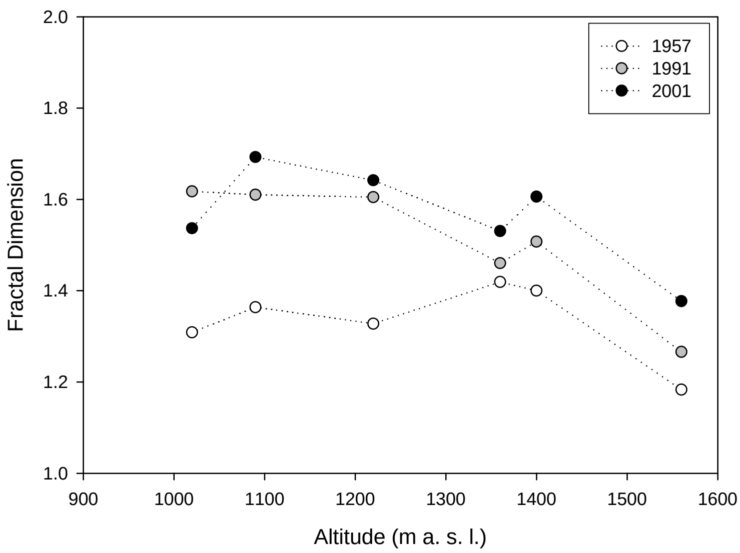

Figure 3 Final (tendency analysis) of the FD obtained for 1957 (empty circles), 1991 (grey circles) and 2001 (black circles).

3.2. FD as indicator of forest change

Significant differences were found between the FD and the corresponding dates (*Figure 3*). The FD from 1975 plots was 1.33 ± 0.08 (mean ± standard deviation), which was lower than the obtained at 1991 and 2001 images: 1.51 ± 0.17 and 1.56 ± 0.11 ($p < 0.05$ and $p < 0.01$), respectively; however, statistically significant differences were not found between 1991 and 2001 plots. Within dates, it appears to be a fall in the FD at those plots located at upper elevation (m a.s.l.). These results suggest that the increased forest cover and vegetation structure diversity reached in the last 50 years can be detected after image FD analysis. In addition, and as stated above, FS may improve the criterion of the forest cover visual delimitation. Because radiometric attributes of images differ among dates, and this radiometric correction is difficult and not at all cases reliable and useful, we consider that the independent classification of each image by mean of a quantitative approach, as the Fractal Dimension Spectrum analysis implemented in *HarFA*, complete and improve any conventional (as visual) criteria.

Acknowledgments

Supported by *Junta de Andalucía* (CVI-302 and RNM-296).

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