SCALAR DATA ANALYSIS FOR ASSESSING BIODIVERSITY OF VARIOUS GEOGRAPHICAL TERRITORIES USING GEOBIA

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ABSTRACT:

Geographic Object Based Image Analysis (GEOBIA) is used in the advancement of spatial object recognition from wider community including landscape analysts. Due to the spatial component inherent in the landscape, the relationship of landscape phenomena to remote sensing and object recognition is well recognised. The landscape phenomena exist and interact in multiple scales. The interaction in multiple scales occurs within the scale and across the scales. To address the issue of this interaction, we developed a scalar data analysis (ScDA) framework in multi-scale environment from remotely sensed data of diverse geographical territories (New Zealand, Nepal and France) by extracting the meaningful image objects, analysing such image objects and relating these image objects to landscape objects. ScDA was applied for the indices such as the Normalised Difference Vegetation Index (NDVI), the Grey Level Co-occurrence Matrix (GLCM), shape index, area, density and asymmetry for image objects. These indices and the developed framework were tested for pertinent scale (the most appropriate scale for analysis) issues using a statistical measure of association – The Relative Interquartile Range (RIQR) and an algorithmic approach. The test result showed that the most appropriate scale to analyse -pertinent scale- can be achieved and is dependent primarily on analysis and interpretation of the objects which are governed by perception, recognition as well as objective of the interpreter / analyst including heterogeneity / homogeneity of the landscape. This methodology showed that pertinent scale issue is relevant for the study of biodiversity monitoring and associated landscape phenomena.

1. INTRODUCTION

In recent years, Geographic Object Based Image Analysis (GEOBIA) is extensively used in extracting knowledge and information from the remote sensing images and in assessing various disciplines including biodiversity. The relationship between remote sensing and biodiversity is well recognised due to the spatial component inherent in the landscape (Aryal et al 2011; Blaschke, 2010; Blaschke, 2005; Lang et al, 2004). Moreover, the landscape can be better understood with hierarchy theory, spatial homogeneity and heterogeneity characters of features at the Earth's surface (Groom et al, 2006; Hay et al, 2003; Marceau et al, 1994). Such characters once studied on nested hierarchies of patch mosaics provide useful information on multi-scales. Multi-scale issues can be better understood by the spatial object concept and the associated attributes. Conceptually, we consider that objects are formed by merging contiguous homogeneous pixels in multiple scales. When we think of merging, there comes a cognitive and perceptual process (Lang, 2008). The attributes of any object contribute in both the process to form candidate-objects in multiple scales. In this study, the thematic, topologic as well as geometric attributes of the image objects are considered to ascertain the pertinent scale (most appropriate scale) for the geographical territory under study. Patch area, number of pixels in forming a patch (density), shape index of individual patch, asymmetry index of individual patch, Normalised Difference Vegetation Index (NDVI) and Grey Level Co-occurrence Matrix (GLCM) of each patch are taken into account to characterise objects. The computational and statistical visualisations of these attributes – ScDA- helped us to determine the most appropriate analysis scale (pertinent scale) in analysing the objects in multiple scales. In this study, our primary objective is to present a geographic object based image analysis methodology to contribute in the *science of scale*. In developing this methodology, we use Landsat images from Nepal and New Zealand. The logic behind in choosing these two sites is that both of these are biodiversity hotspots of the world (Myers et al, 2000). Further, we also use a SPOT image from Mount Ventoux, a biosphere in south of France.

The main goals of this experiment were to visualise the associated scalar data of different indices in multi-scales in seeking a most appropriate scale to analyse the spatial objects. Such indices were tested for the image objects and realised for the landscape objects of the diverse geographical territories. Within this framework, in this paper, we aim to answer to the following questions:
Do the characteristics of image objects and landscape objects help to analyse and extract the information in monitoring the spatial pattern and processes of landscapes? Are there relevant scales to be used to depict certain types of geographical objects? Are the scalar data analysis methods helpful in suggesting hypotheses about the causes of observed geographical territories and associated phenomena? What are the governing factors for the optimal scale of analysis for geographical image objects?

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In general, what kind of methodology could be designed to address the issues raised above? In answering these questions, we focused ourselves in extracting the image objects and corresponding landscape objects in multiple scales, calculating the relevant indices, visualising and testing them for scalar data analysis.

The organisation of the paper is as follows: in section 2, we present the data and adopted methodology. In section 3 the results are presented along with ScDA and algorithmic approach. Section 4 presents the discussions and conclusions. Section 5 presents future works.

2. DATA AND METHODOLOGY

A Landsat 7 Enhanced Thematic Mapper (ETM) image of December 2001 is acquired for the New Zealand site - Christchurch city and surroundings. The imagery is having 0 % cloud cover and is from high vegetation growth season. Similarly, another ETM image of May 2011 is acquired for the Nepal site - Kathmandu city and surroundings. The image is acquired from the United States Geological Survey (USGS, 2011). Likewise, a SPOT image of 2004 is acquired for the France site – Mount Ventoux, South of France. The spatial resolution of the satellite image is 25 m for the New Zealand site, 30 m for the Nepal site and 2.5 m for the France site.

The remote sensing image analysis was performed in Object Based Image Analysis (OBIA) software (www.ecognition.com) – eCognition (Trimble, 2010). This allowed us to implement expert knowledge, to generate homogeneous objects through a local optimization procedure, and to create a hierarchical framework of decomposable image objects (Benz et al, 2004; Hall et al, 2004). Many works have demonstrated its usefulness in landscape habitat mapping (Mathieu et al. 2007; Lathrop et al, 2006). Vegetation patch visualisation is performed in ESRI ArcGIS/ArcInfo (http://www.esri.com/software/arcgis/arcinfo/index.html) and numerical / statistical modelling of various biodiversity indices were performed in the statistical data language GNU R (http://www.r-project.org/). The optimum segmentation parameters were determined using a systematic trial and error approach validated by the visual inspection of the image objects. In this study, the colour criterion was assigned a weight of 0.9 and the shape received the remaining 0.1 (compactness 0.5 and smoothness 0.5) as these two are complementary. Five levels were generated in hierarchy namely for scale indexed by scale factors 20, 50, 100, 150 and 250 to extract the meaningful image objects, to analyse and to test for the pertinent scale issues.
Hierarchical segmentation of a section of the study area is presented for New Zealand's site (Figure 1). This shows spatial aggregation of features across the scales in a hierarchy. We developed the models to test the extracted image objects of vegetation patches and visualised for scalar statistical distribution. After visualisation, we chose three indices (NDVI, Shape index and GLCM entropy) in observing the "global pertinent scale", by using a statistical measure of association, the Relative Interquartile Range (RIQR).

$$RIQR = \left| \frac{Q_3 - Q_1}{Median} \right| \qquad (1)$$

Where, Q_3 = 3rd quartile and Q_1 = 1st quartile

Further, we use visual approach in combination with developed algorithm to ascertain "local pertinent scale".

The considered attributes have specific characters in studying the vegetation science and biodiversity in particular. As for an example, NDVI is strongly related to the extent of vegetation cover and is an indicator of both landscape heterogeneity (Kerr and Ostrovsky, 2003) and biological diversity (Gillespie et al, 2008; Oldeland et al, 2010). Similarly, the shape index describes the smoothness of an image object border. The smoother the border of an image object is, the lower its shape index (eCognition, 2010). If the border of the objects is smoother the biodiversity is lower due to the reduction of potential contacts between different types of landscapes. GLCM index is an important one for the vegetation / plant study due to the texture feature which is prominent in describing the vegetation.

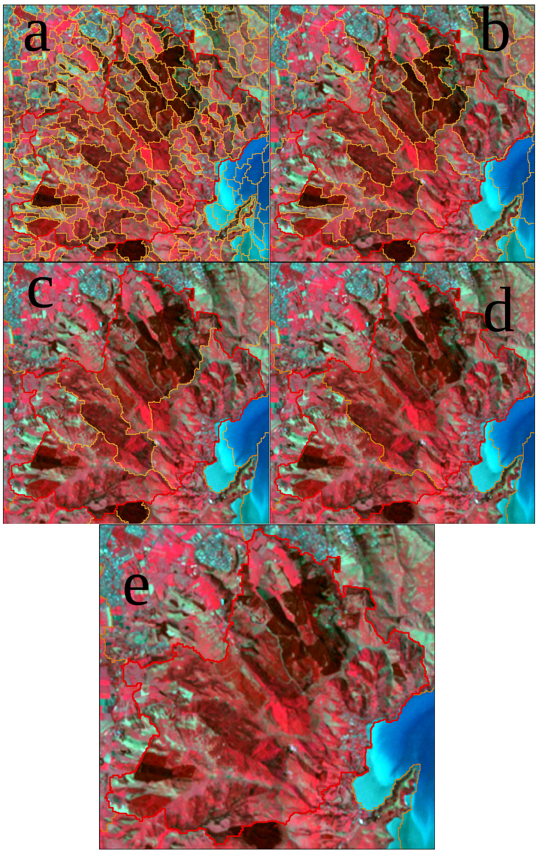


Figure 1: A section of the study area showing the spatial aggregation across five scales a) level 1 at 20 scale, b) level 2 at 50 scale, c) level 3 at 100 scale, d) level 4 at 150 scale and e) level 5 at 250 scale for a representative patch from New Zealand site.

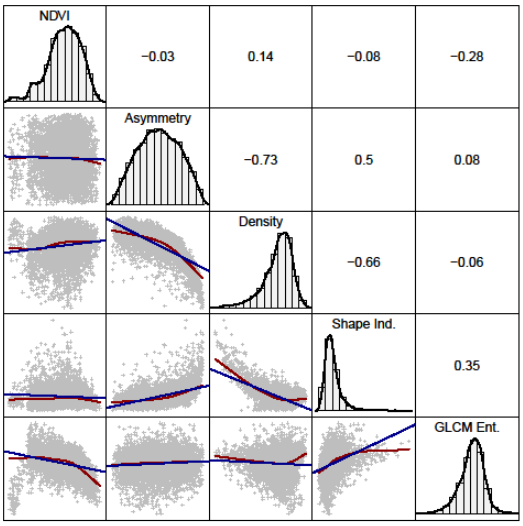
3. RESULTS

As our interest in this study is to analyse the multi-scale issues associated with satellite images from different geographical territory and indices (attributes) linking to biodiversity, we produced results in the scaling domain for selected attributes. Our results are for (i) statistical visualisation of patch attributes, (ii) visualisation of global pertinent scale for selected indices, and (iii) visualisation of local pertinent scale by an algorithmic approach.

3.1 Statistical visualisation of patch attributes

Among the indices, we observed their relationship in terms of correlation coefficient and statistical distribution (Figure 2). All the indices presented are independent variables. We wanted to observe whether there is a strong relationship (described by collinearity) among the variables in order to select the most relevant ones. As an example, in the New Zealand case, the results showed that asymmetry and shape index have a correlation coefficient of 0.5, so we should only keep one of them. Further, we considered the ecological and statistical significance of each index for both sites. From the ecological perspective, shape index has a more significant impact than asymmetry.

With this fact, we choose three indices – NDVI, shape index and GLCM entropy - for observing and extracting further information for all the three sites.



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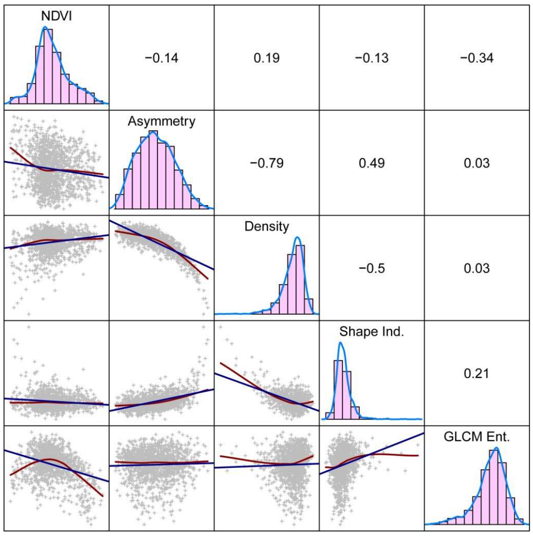

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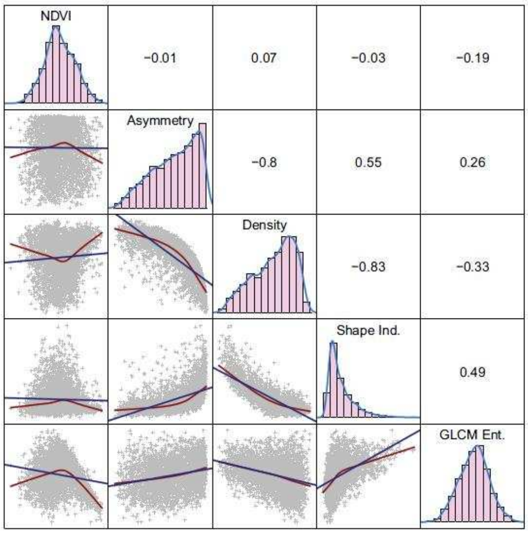

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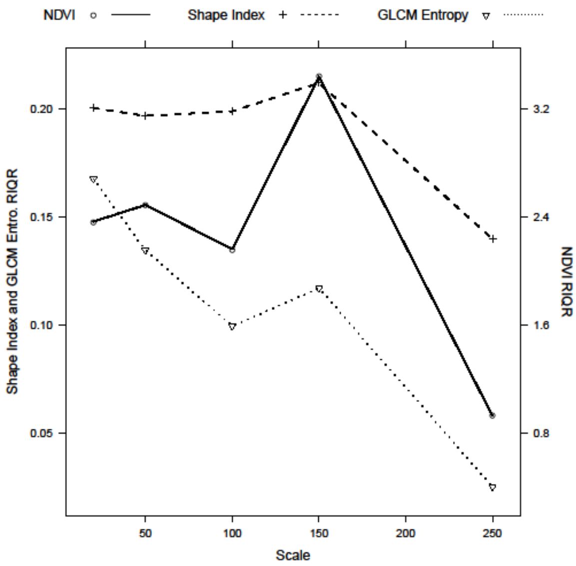
Figure 2 Statistical distribution and correlation coefficient visualisation to ascertain the association between the attributes of patches (a) New Zealand site (b) Nepal site (c) France site.

3.2 Visualisation of global pertinent scale for selected indices

The global pertinent – most appropriate to analyse- scale was computed using RIQR methodology taking into the aspect of robustness. As the median is more robust among the descriptive statistical measures, we assume that, RIQR gives a robust measure. In ascertaining the pertinent scale using this methodology we observed the maximum variability among the scales and minimum variability within the scales (Figure 3). For New Zealand site we observed that scale 150, for Nepal site scale 250 and for France site scale 100 are pertinent. With this result, we further observed that some patches are not disintegrated across the scales and some are throughout the scales. This motivated us to investigate the local pertinent scale for individual patches by using an algorithmic approach.



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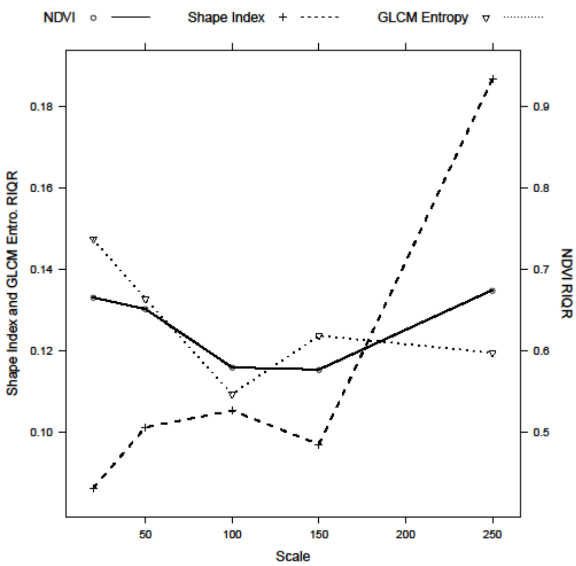

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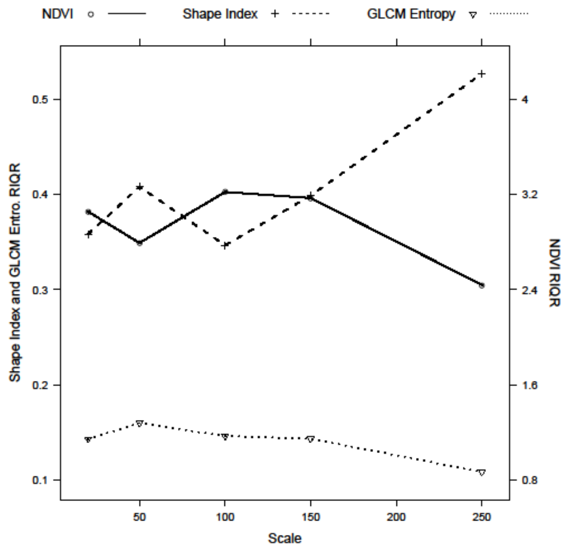

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Figure 3. The measurement of variability with relative interquartile range of indices namely NDVI, Shape Index and GLCM Entropy in multi-scales (a) New Zealand site and (b) Nepal site and (c) France site.

3.3 Visualisation of local pertinent scale by an algorithmic approach

According to our definition and assumption and based on the attributes of patches, the global pertinent scale for New Zealand site is 150 scale, for Nepal site it is 250 scale and for France site it is 100 scale. We noticed the irregular disintegration of patches within the pertinent scale in the maps; we investigated for local pertinent scale. To further explore the local pertinent scale of individual patch, we used spectral analysis (visual approach) with the following algorithm for all the sites;

1. *Observe each patch at the global pertinent scale and every finer scale in a top down approach;*
2. *When a patch is not disaggregated from the pertinent scale to the next scale, keep the global scale as the local pertinent scale for the patch;*
3. *If the patch keeps disaggregating then select as the local pertinent scale at which the patches created from the disaggregation maximize NDVI's RIQR.*

In the case of New Zealand site we found 29 patches for which we visualised the pertinent scale by observing RIQR across the scales. Out of 29 patches, 19 patches are pertinent to analyse in scale 20, 7 patches in scale 50 and 3 patches in scale 100.
In the case of the Nepal site, 4 patches are further disaggregated of which 2 patches are pertinent to analyse in scale 20, 1 in scale 100 and 1 in scale 150. Similarly, in the France site, this phenomenon exists too.

The above analysis of global pertinent scale and local pertinent scale for individual patch helped us to understand the landscape and the analysis scale. This is dependent on the geographical territory under study and the real world features in the landscape

4. DISCUSSION AND CONCLUSIONS

In dealing with complexity such as landscape phenomena, it is very important to study the combination of indices for an effective interpretation of landscape pattern and their association to ecological processes. In analysing our results in terms of appropriate scale of analysis, we tried our best to fit the objects taking into account the lower scale, focal scale and upper scale. The focal scale is the pertinent (optimal) one for specific diversity analysis for the objects under consideration. The focal scale is the representation of reality taking many factors into account, such as: perception versus delineation, conceptual boundary versus real boundary of the features, existing classification key versus mapping schemes, subjectivity versus objectivity and most importantly interpretation versus analysis. With the available tools for analysis and visualisation along with algorithmic approach we have different results for three different sites. In the New Zealand site, we observed that 150 scale is globally pertinent while in the Nepal site, this is 250 scale. In the case of France site the optimum scale is 100. Within the global pertinent scale, the local pertinent scales are different according to the relative interquartile range of spatial attributes. This showed us that pertinent issue is not only associated with interpreters' objective it is also associated with the territory and its content and the homogeneity. Furthermore, as discussed above, visualisation of the boundary of geographical features is conceptual boundary interpreted by interpreter rather than a 'real' geographical boundary. We are aware that in the entire process of GEOBIA the ultimate benchmark is our visual perception and the tool is supportive and it reacts on parameters although the expert has to decide (Lang, 2008). In observing the specific sites, the New Zealand site and its territory is heterogeneous and constitutes of sea, city, and plantation. On the other hand in the case of Nepal site, it constitutes a city and a homogeneous vegetation area of 'Shivapuri National Park'. In the case of France site, the study area is a nature reserve primarily dominated by protected vegetation types. The results further showed us that the pertinent scale issue is governed by the land cover of the area under study.

We have revealed that GEOBIA in conjunction with the landscape indices is capable enough to characterise the landscape objects with a scalar data analysis in a hierarchical patch dynamics scenario. Among many variables, we considered the thematic, geometric and topological attributes of image objects and corresponding landscape objects for multiple scales. We considered biodiversity assessment using NDVI in particular. We are aware that observing the patterns of nature and comparing those patterns in diverse geographical territories is not a straightforward task and it demands the consideration of many other characteristics.

5. FUTURE WORK

With the perspectives and conclusions drawn from this study it is possible to refine and extend the current framework in the *science of scale*. The refinements could be made by developing a robust and generalised methodology to analyse the landscape of diverse geographical territories. Such methodology will take into account the definition of the landscape characters in terms of structured objects in multiple scales. Such a methodology would open up further research in diverse areas including landscape ecology and ecological processes like climate change issues. Possible areas of extension would be in the statistical computation and visualisation for informed decisions of landscape characters using scalar data analysis. We would like to test the hypotheses for the causes of observed phenomena in describing the landscape objects and in providing a basis for validating the results using the primary data.

With the inclusion of such refinements and extensions, we do hope that we will be able to characterise the landscape objects and their association to pertinent scale which indeed helpful in understanding the pattern and processes of landscapes. Further, this will contribute to GEOBIA's key theoretical and methodological issues, trends and challenges.

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