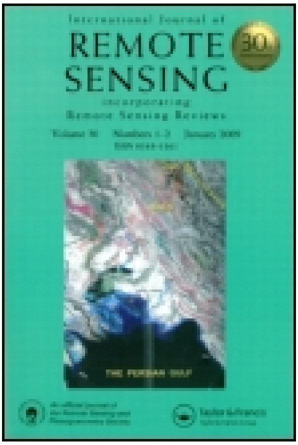

International Journal of Remote Sensing
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tres20

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Published online: 25 Nov 2010.

INT. J. REMOTE SENSING, 2001, VOL. 22, NO. 13, 2627–2632

Texture analysis of IKONOS panchromatic data for Douglas-fir forest age class separability in British Columbia

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(*Received 20 October 2000; in final form 2 February 2001*)

Abstract. This Letter presents the results of textural separability tests obtained by first- and second-order texture methods on different aged Douglas-fir stands in IKONOS panchromatic imagery acquired 3 June 2000 over the Sooke River watershed in British Columbia. The effects of different measures and window sizes on the textural separability are discussed. Small windows sizes were not as effective in separating stands as larger windows sizes. Second-order (spatial co-occurrence homogeneity) texture values were the most effective in distinguishing between age classes. A first-order (variance) texture measure, though still useful, provided less separability.

1. Introduction

Texture is a key *visual* criteria when interpreting information on the spatial distribution of forest vegetation from aerial photographs (Graham and Read 1986, Lillesand and Kiefer 1994). This use of texture flows naturally from the powerful innate ability that humans have in recognizing textural differences, although the complex neural and psychological processes by which this is accomplished have so far evaded detailed scientific explanation (Hay *et al.* 1996). With the increased availability of new high spatial detail digital imagery, from airborne platforms (Anger 1999) and satellite platforms (Barnsley 1999), it is apparent that, increasingly, *digital texture* should be considered a potentially important information source for forestry purposes (Green 2000). Insight into how texture might be analyzed by computer has focused on the structural and statistical properties of textures (Haralick 1986). Texture is a complex *multiscale* phenomena (Ahearn 1988), but there are few guidelines available to help forestry users conduct a texture analysis with high spatial detail digital imagery.

Forest stands have been separated by differences in digital texture related to species composition (Franklin *et al.* 2000), age-class and structure (Cohen *et al.* 1990), and crown closure (St-Onge and Cavayas 1995, 1997). Our intention in this Letter is to examine IKONOS panchromatic imagery, with an original image acquisition spatial resolution of 0.82 m, for textural differences in stands of Douglas-fir, to

International Journal of Remote Sensing
ISSN 0143-1161 print/ISSN 1366-5901 online © 2001 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/01431160110053590

determine whether commercially-available first- and second-order texture measures are useful in identifying differences related to age classes of trees. Knowledge of differences in forest age class is currently considered a necessary component in sustainable forest management planning and practices (e.g. Spies 1997).

2. Study area and methods

The study area is located in the Sooke region in the southern portion of Vancouver Island, British Columbia, Canada (centered near 48.58° N, 123.72° W). This area is located within the Pacific Maritime ecozone. Within the forested land, the dominant tree species include Douglas-fir, western red cedar, and hemlock (Wulder *et al*. 2000). A cloud-free IKONOS panchromatic image was acquired on 3 June 2000 (figure 1). The solar elevation was 60.7° and the solar azimuth was 146.5°. The image was georeferenced to a vector photointerpreted forest inventory coverage stored within a geographic information system (GIS) database. Data in the GIS species composition and age class categories, as defined by the provincial forest inventory system (Gillis and Leckie 1993), were used to stratify the database into pure Douglas-fir stands for several age groups (table 1).

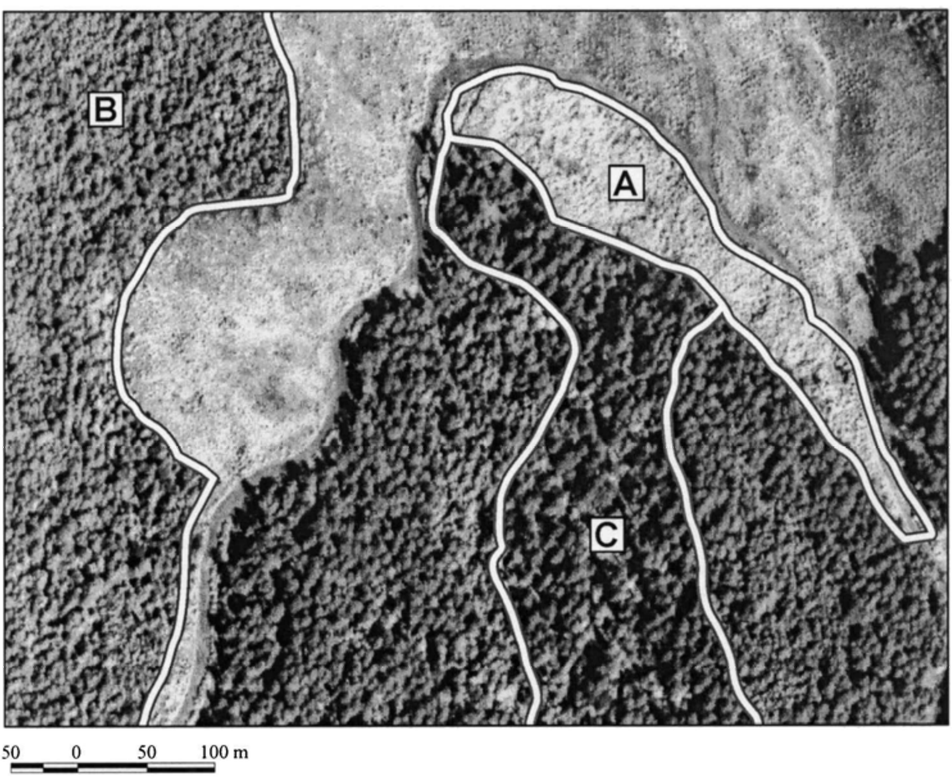

Figure 1. A sub-area of the IKONOS image showing locations of three different age classes sampled for texture; A indicates forest age class 2 (21–40 years), B indicates forest age class 5 (81–100 years), and C indicates age class 9 (+251 years)

Table 1. British Columbia forest inventory age classes.

Age class	Age limits (years)
1	1–20
2	21–40
3	41–60
4	61–80
5	81–100
6	101–120
7†	121–140
8	141–250
9	251+

†Age class absent in study area.

Within three or four stands of each age class, 20 pixel locations were selected near the stand centre. At these locations, one first-order (variance), and one second-order (homogeneity) texture measures were derived:

$$\text{variance} = \frac{\sum(x-\bar{x})^2}{n-1} \quad (1)$$

$$\text{homogeneity} = \sum_i \sum_j \frac{P(i, j)}{1+(i-j)^2} \quad (2)$$

where $P(i, j)$ is the spatial co-occurrence matrix. Three different moving window sizes were used (5×5, 15×15 and 25×25) based on an initial analysis of Queen's case semivariograms (eight cardinal directions) to determine the approximate area over which pixel variations occurred (Franklin *et al.* 1996). The high spatial resolution of the imagery resulted in a semivariance spatial domain relating individual tree rather than stand level characteristics. The principle behind using first-order (i.e. variance-based) and second-order texture (i.e. derivative-based) is simple: 'texture information is contained in the overall, or "average", spatial relationship which gray tones in the image have to one another' (Haralick *et al.* 1973).

A one-way analysis of variance (ANOVA) was performed to determine if a significant difference (at $p<0.05$) existed between mean texture values for each age class. The magnitude and significance level associated with each ANOVA F value were used to determine the most effective texture measures, and window sizes, in separating the various age classes. A larger F value indicates greater separation. Since ANOVA results do not distinguish which age classes differ from one another, the Bonferroni multiple mean test was also applied to identify where significant differences occurred between class pairs. The Bonferroni multiple mean test adjusts the overall significance level based on the number of pairs being compared (Neter *et al.* 1990).

3. Results

The ANOVA tests demonstrated that there was a significant difference (at $p<0.05$) in the mean texture values of the age classes for each texture measure, and window size combination, except the variance texture measure using a 5 pixel × 5 pixel window (table 2). Greater separation between age classes was achieved using the 25 pixel × 25 pixel windows than the smaller pixel windows, as indicated by the larger F values of the former. Further, greater separation between age classes was achieved using the homogeneity measure ($F = 39.6$, $p < 0.0001$) than the variance measure ($F = 17.4$, $p < 0.0001$).

Tabular results provided from Bonferonni analyses, showing separability between age classes based on the mean texture values obtained from each class are lengthy, and consequently a detailed presentation of all results was not practical here. Instead, a summary of the trends observed is shown graphically in figure 2 in which the grey regions within each triangle indicate a significant difference (at $p < 0.05$) existed between the mean texture values for the specified age class pair. No significant difference existed between mean texture values obtained from each age class with the 5 × 5 variance texture measure. However, as the variance window size was increased, the number of significantly different age class pairs increased. For example, age class 9 was found to be significantly different from all other age classes with the variance texture measure in a 15 × 15 window. As the window size was increased to 25 pixels × 25 pixels, the younger age classes (2 and 3) were distinguished from the youngest age class (1), and a significant difference was detected between age class 1 and the two oldest age classes (8 and 9). Again, class 9 was statistically different from all other classes. While these results were relatively poor in respect to separation of many classes (i.e. fewer classes were separable), they followed the trend of increasing F value and pair separation with an increased window size.

The trend was demonstrated further with the homogeneity texture measure. Distinction between mean homogeneity values from each age class pair increased as the window size increased from 5 × 5 to 15 pixels × 15 pixels. At the smallest window size, only young and old age classes could be separated (i.e. age classes 1 to 3 paired with age classes 6 to 9). However, as window size increased to 15 pixels × 15 pixels, the middle age classes could also be separated from the younger and older age classes. While the magnitude of the ANOVA F value was highest with the 25 pixel × 25 pixel homogeneity measure, no additional distinction between remaining age class pairs was provided; the Bonferroni test did not show increased separation between any other age class pairs as a result of the more significant distinction between age class pairs resulting from a larger difference in mean texture values.

4. Conclusions

Texture features in high (fine) spatial resolution airborne and satellite sensor imagery contain forest information, and may be employed to increase the utility of high spatial resolution imagery as a useful source of information. Digital texture is

Table 2. ANOVA results.

Window size	Variance F	Homogeneity F
5 × 5	1.7	5.6*
15 × 15	10.1*	30.0*
25 × 25	17.4*	39.6*

Marked (*) F values significant at $p < 0.05$.

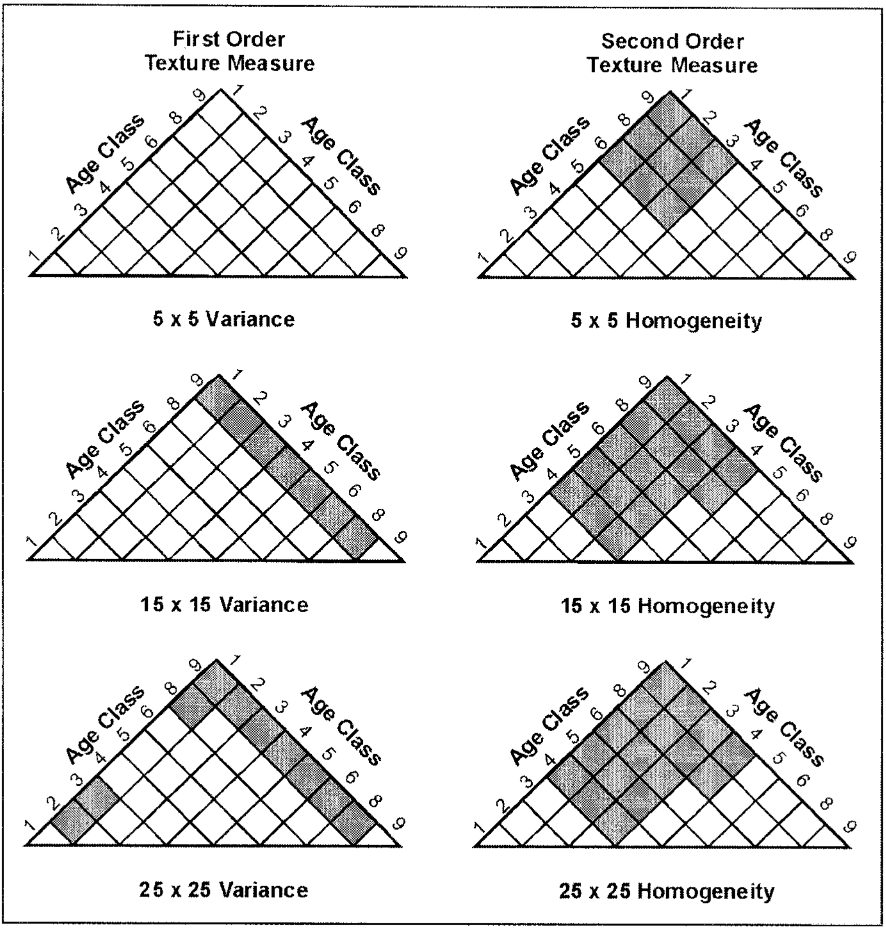

Figure 2. Graphical results of Bonferroni multiple mean comparison test; shaded areas indicate significant separability between two age classes.

a complex concept and application in remote sensing. Tools for texture analysis in most public or commercially-available image processing systems are fragmented and poorly developed, but many such systems provide first- and second-order texture functionality. We hypothesized that these relatively simple textural measures, with different window sizes, would be useful in separating different forest age classes in IKONOS panchromatic imagery. Second-order (spatial co-occurrence homogeneity) texture obtained from the larger pixel windows was most effective for distinguishing stands in different age classes. A first-order (variance) measure provided a weaker separation over the same window sizes. The variance texture measure may be complementary to the homogeneity measure.

Acknowledgments

This research was funded by the National Sciences and Engineering Research Council of Canada and the Canadian Forest Service. Helpful comments by the anonymous reviewers were greatly appreciated.

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