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Full Length Research Paper

Detection of ecotone environment based on satellite and field techniques (A case study; Northern Alborz, Iran)

Karim Solaimani* and Fatemeh Shokrian

GIS & RS Centre, University of Agriculture and Natural Resources, P. O. Box 737, Sari-Iran.

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Environmental change and socio-economic pressure are expected to have significant impacts on Northern Alborz vegetation, particularly along ecotone such as the treeline. Remote sensing may be well suited to monitoring recent changes across the treeline because it captures integrated changes of all vegetation life forms over large spatial extents. This research examines treeline vegetation composition and change along the Nojmeh treeline using a high resolution, ETM$^+$ 2000. In this paper we investigate the use of satellite data to produce a classification of a treeline ecotone in Northern Alborz Mountains which has supported the field investigation as ground truth data collected in the summers from 2008 to 2010. The maximum correlation is related to the Bands 3 and 4 of Landsat ETM$^+$ with shrubs canopy cover that indicated in r of 0.34 and 0.37 respectively. The maximum rate of correlation in respect to the indices were recognized for the vegetation cover of moisture stress index (MSI) for forbs cover (r= 0.62). The ratio vegetation index (RVI) for grasses cover was indicated (r= 0.53). In conclusion, the results are specified that the ETM$^+$ sensor is the significant data with the elevated competence to discrimination of ecotone using vegetation indices.

Key words: ETM+, classification, ecotone, treeline, Alborz, Iran.

INTRODUCTION

Satellite remote sensing has advantages for monitoring vegetation composition and treeline detection due to its ability to monitor all vegetation life forms simultaneously. The tree line or ecotone is the boundary of the habitat at which trees are capable of growing. Beyond the tree line, they are unable to grow because of inappropriate environmental conditions. An ecotone is a transition area between two adjacent ecological communities or eco-systems. It may appear on the ground as a gradual blending of the two communities across a broad area, or it may manifest itself as a sharp border line. Vegetation changes along this ecotone will alter vegetation–land use interactions and eventually climate. These changes will also have implications for people who depend on ecosystem, such as woodland across East to Western direction of the study area. The treeline represents a transition zone between continuous forest and rangeland.

Although the gradient that defines the treeline is based on tree density characteristics, there are other important compositional changes that occur along the latitudinal treeline gradient as well. Analyses of temporal vegetation change along the treeline have focused mainly on trees and have generally been investigated using field and satellite techniques. In digital satellite data of the Landsat ETM$^+$, an ecotone may appear as an edge, a boundary of mixed pixels or a zone of continuous variation, depending on the spatial scale of the vegetation communities and their transition zone in relation to the spatial resolution of data. Often on stereoscopic image, an ecotone is observed clearly, or part of it may be mapped as a separate vegetation community if it covers an area of several pixel widths. A soft classification method, such as probability mapping, is inherently appealing for mapping vegetation transition. Ideally, the probability of member-ship of each pixel has vegetation class that corresponds with the proportional composition of vegetation classes per pixel. Clements in 1905 introduced ecotone as a zone of alteration between two individual vegetation commu-nities. These unique ecosystems can have higher

*Corresponding author. E-mail: solaimani2001@yahoo.co.uk. Tel: (+09)9111521858

Biodiversity than either neighboring community (Backage et al., 2008) which helps maintain species flows between them (Baker et al., 2002). Furthermore, ecotones can persuade the fluctuation of materials and energy in the landscape and can be early indicators of ecological reaction to environmental change (Di Castri et al., 1988). The determination and monitoring of ecotones therefore has a vital role in our understanding of biodiversity distribution and the policies that are put in place to enhance it. Ecotones can be classified as 'environmental' or 'anthropogenic', resulting from either natural or human-induced environmental transition over space, as 'invasion' where there is invasion of a dominant species along a front, or as 'switch' where there is a positive feedback between vegetation community and environment (Walker et al., 2004). The transition with altitude from dense forest to the rangeland represents an ecotone gradient relating to increasingly harsh environmental conditions (Smith et al., 2003). Clearly, where an ecotone is determined by an environmental gradient, its nature and spatial configuration are highly prone to environmental changes (Malanson, 2001). Apart from human impacts, the local scale environmental factors such as topographic complexity, geology, disturbance patterns and biotic interactions also influence its relevance (Alftine and Malanson, 2004; Wu et al., 2007). A more detailed assessment of ecotones using Landsat TM images was provided by Allen and Walsh (1996), who investigated the treeline ecotone in Glacier National Park, Montana, and used a hierarchical approach to create a supervised classification of six forest types and five non-forest vegetation types (Nelson et al., 2004, Wiegand et al., 2006, Foody, 1992, 1996). Alternatively, soft procedures exist such as linear-mixture modelling (Quarmby et al., 1992) or fuzzy clustering (Cannon et al., 1986) which seek to unmix the composition of pixels, for example, at land-cover boundaries (Fisher and Pathirana, 1990; Foody and Cox, 1994). Ranson et al. (2004) used a Landsat enhanced thematic mapper (ETM^+) image, amongst others, for assessing the tundra-taiga ecotone in Russian Siberia. The classification probability or membership function for a vegetation class may correspond with the proportional composition of that vegetation class for the area covered by a pixel. However, the probability or membership image for a vegetation class cannot by itself represent an ecotone, since an ecotone is a transition from one vegetation type to another. However, this must take into account both end-member classes and it places subjective inflexible boundaries onto the landscape. The decision of where to delineate the alpha-cuts will have a significant impact on the spatial characterisation of an ecotone and any derived landscape pattern metrics (Arnot et al., 2004; Shi et al., 2008). There is no optimal technique of delineating ecotone boundaries (Fortin et al., 2000) and yet to understand the processes involved in the formation and maintenance of ecotones, and to monitor their stability over time, it is necessary to delineate them accurately (Fortin and Drapeau, 1995). This paper investigates the use of class probability mapping to produce a classification of an ecotone in Alborz using a Landsat ETM dat. It can be mapped for the treeline ecotone as a zone of alteration of some transitional vegetation classes between forest and treeless vegetation.

MATERIALS AND METHODS

Study area and material

The field site is located in the Northern flank of Alborz Mountains, approximately between 36° 14' 26" to 36° 25' 54" N. and 52° 01' 46" to 52° 12' 30" E. in Upper Vazroud, in the south of the Caspian Sea. The area lies in the Central Alborz, where is mainly sandstone rocks and clay. The field site includes two ecosystem regions from highland to the forest zone, all within the Central Alborz zone. In the high mountains, the dominant vegetations are related to the rangeland and the forest area is covered by broadleaf species (Figure 1). It is situated between 1840 to 2650 m above sea level, has an Alborzian cold to semi arid climate with mean annual temperature and precipitation of 10.6°C and 800 mm respectively (Solaimani, 2008). From 14123 ha of the study area 5000 ha is belonged to the rangelands.

Landsat enhanced thematic mapper (ETM^+ data)

The grassland vegetation growth peak period in Noujmeh upland of Vaz watershed occurs during the 2nd half of June. However, this period often corresponds to high cloud covers and thus limits the selection of cloud free images. All available landsat-multi spectral scanner (MSS), thematic mapper (TM) and enhanced thematic mapper (ETM+) images in our remote sensing centre's archives were reviewed for the growth period and cloud free images were selected (Table 1). Because of the lack of satellite images for period 2009 and 2010, the years when we conducted major field work, a cloud free Landsat (ETM^+), 30 m spatial resolution image, was used for this period.

A total of 32 training areas were identified in the field to capture the stereoscopic variance of the used images scene components. These included components that were not relevant to mapping the ecotone (cloud shadow, water bodies, bare soil, pasture and river channels) and components that were of relevance (bare rock, sparse herbaceous vegetation, natural grass, scrub, and forest of different age and species composition). These training data were used for visual classification of the two colour and panchromatic images. Due to the remote and rocky nature of the study area and difficulty of measuring field plots on a large scale, justification data for this study were derived from high spatial resolution aerial photographs (1: 50000) provided from the Iranian Geographical Organization. This is a standard consideration in studies validating the production of an image classification (Foody et al., 2003; Wang, 1990). Two different tests were carried out to investigate whether the posterior probabilities of class membership related to vegetation composition; the first at a pixel level (that is, 10 × 10 m) and the second at a quadrate level (that is, up to 200 × 200 m). To identify whether the posterior probabilities related to the proportional vegetation cover per quadrate, two scanned and ortho-rectified, 1:20000 scale, colour aerial photographs were used to derive the proportional cover of trees-shrubs and grass-herbaceous vegetation in 12 sample quadrates. The distinction between trees and shrubs and between grass and herbaceous vegetation could

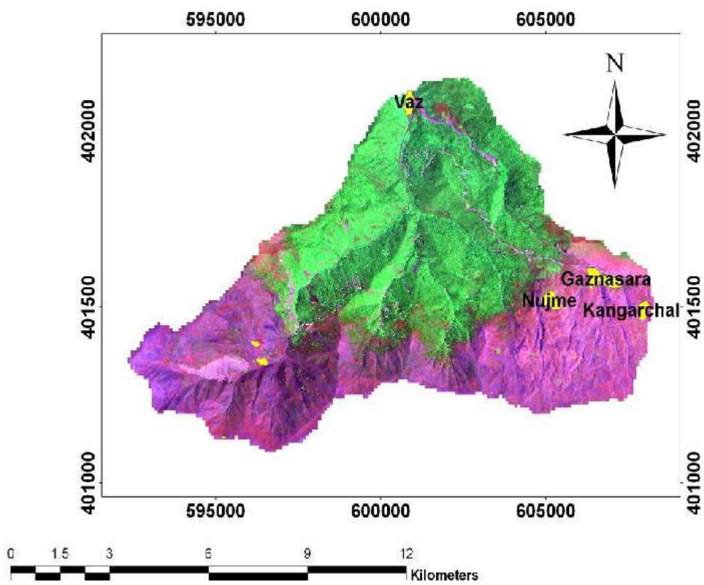

Figure 1. Location of the study area related to Iran.

Table 1. Date, source and characteristics of the used satellite image.

Date	Source	Resolution (m)
2000 June 18	Landsat ETM+	30
1990 June	Cosmos KFA-1000	8-10

not be made routinely by this visual interpretation method. This analysis gave an estimate of the percentage canopy cover of trees/shrubs and of grass/herbaceous vegetation per quadrate. Relationships were examined between the average posterior probability for 'scrub and forest' and for the two non-forest vegetation classes combined. This indicated the significance of the posterior probabilities of class membership at a spatial scale greater than that of the individual pixel representing the treeline ecotone. For this study the treeline ecotone was considered as a transition between upland examples of 'scrub and forest' and the non-forest vegetation classes of 'pasture and natural grass' and 'sparse herbaceous vegetation'. For ease, the posterior probability of class membership for 'pasture and natural grass' and 'sparse herbaceous vegetation' are combined as a single vegetation class (called 'non-forest vegetation') for the remainder of this paper. To map this transition two different approaches were used, although both approaches were applied only to those pixels for which the combined posterior probability for 'scrub and forest' and 'non-forest vegetation' was 90%. In the first approach, stereoscopic method were applied to the posterior probability of 'scrub and forest' to separate two last component vegetation communities and the transitional classes.

RESULTS AND DISCUSSION

The red treeline were extracted on both panchromatic and colour images for 'scrub and forest', 'pasture and natural grass' and 'sparse herbaceous vegetation' is determined clearly with better resolution in ETM+ and colour KFA-1000 image than the gray one. The grey scale images of the KFA-1000 in dark tones have low resolution of probability border of the forest in class membership and the colour tones have high resolution (Figures 2, 3 and 4).

In these probability images, the boundaries are ecotones between scrub and meadow/herbaceous vegetation in the upland areas. The two colour and panchromatic images show a decrease in the natural border line of different vegetation cover of forest and rangeland types and a corresponding increase for grass and/or herbaceous vegetation with increasing elevation. The proportional cover of trees/shrubs and of grass/ herbaceous vegetation in the 12 quadrates sampled in the aerial photographs ranged from 90 and 6% respectively to 9 and 89% respectively. The relationships between the posterior probability of class membership for 'scrub and forest' and 'nonforest vegetation' and the percentage ground cover of these vegetation classes were positive and highly significant: r^2 = 0.85 and r^2 = 0.87 respectively. Although the posterior probability image for 'scrub and forest' was shown to be meaningful in terms of forest composition, this was not by itself sufficient to represent fully the treeline ecotone, since the transition was between 'scrub and forest' and the non-forest vegetation classes of 'pasture. This would be

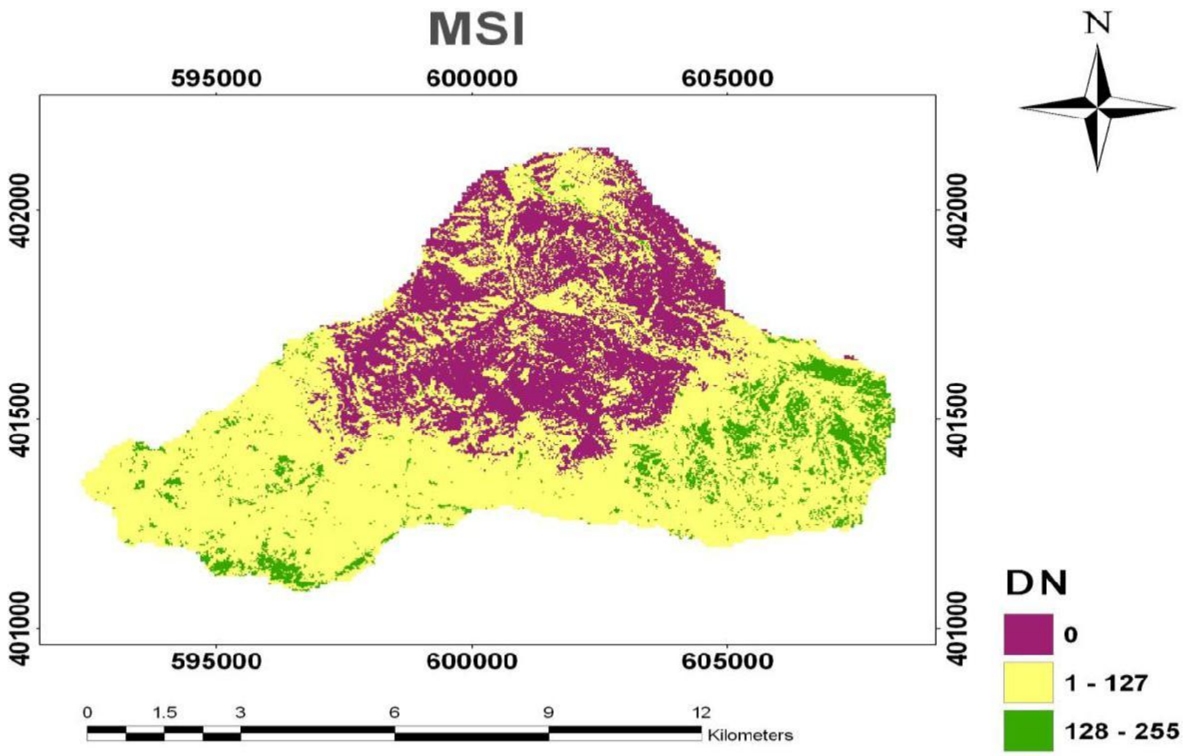

Figure 2. The border of treeline marked between yellow and brown colours, using MSI index (source; ETM+ of 18 June, 2000).

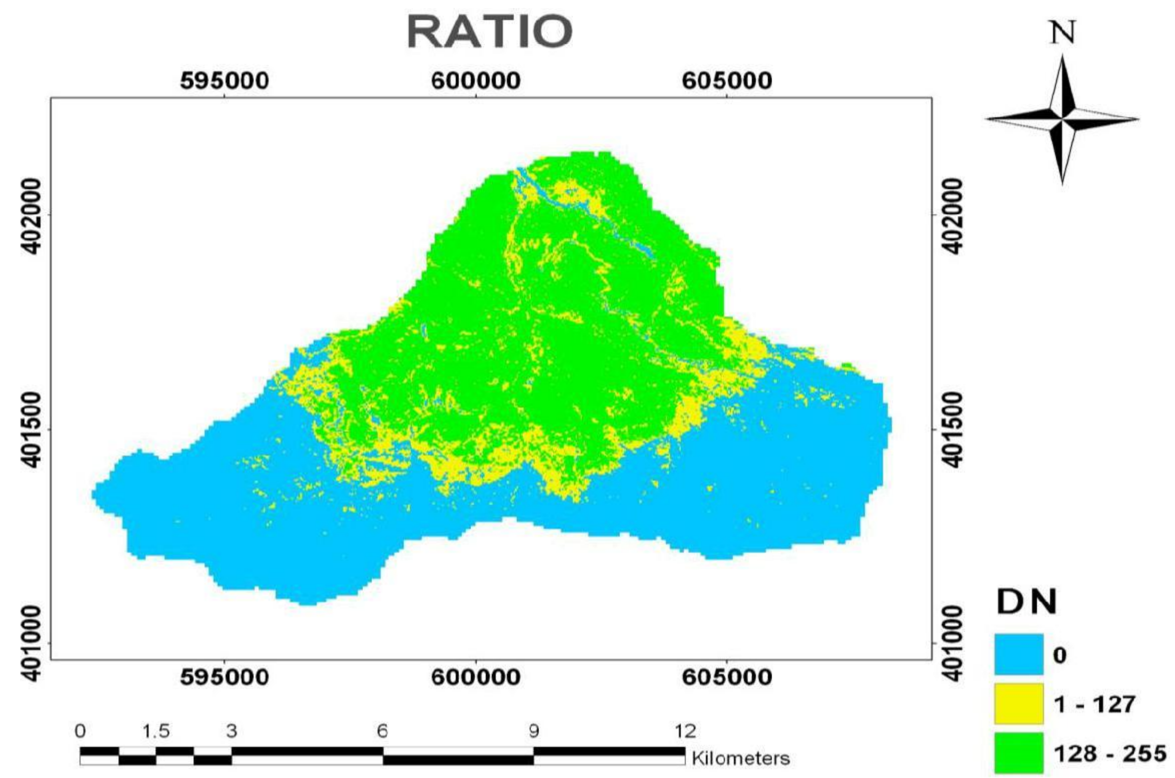

Figure 3. The border of treeline marked between blue and green colours, using Ratio index (source; ETM+ of 18 June, 2000).

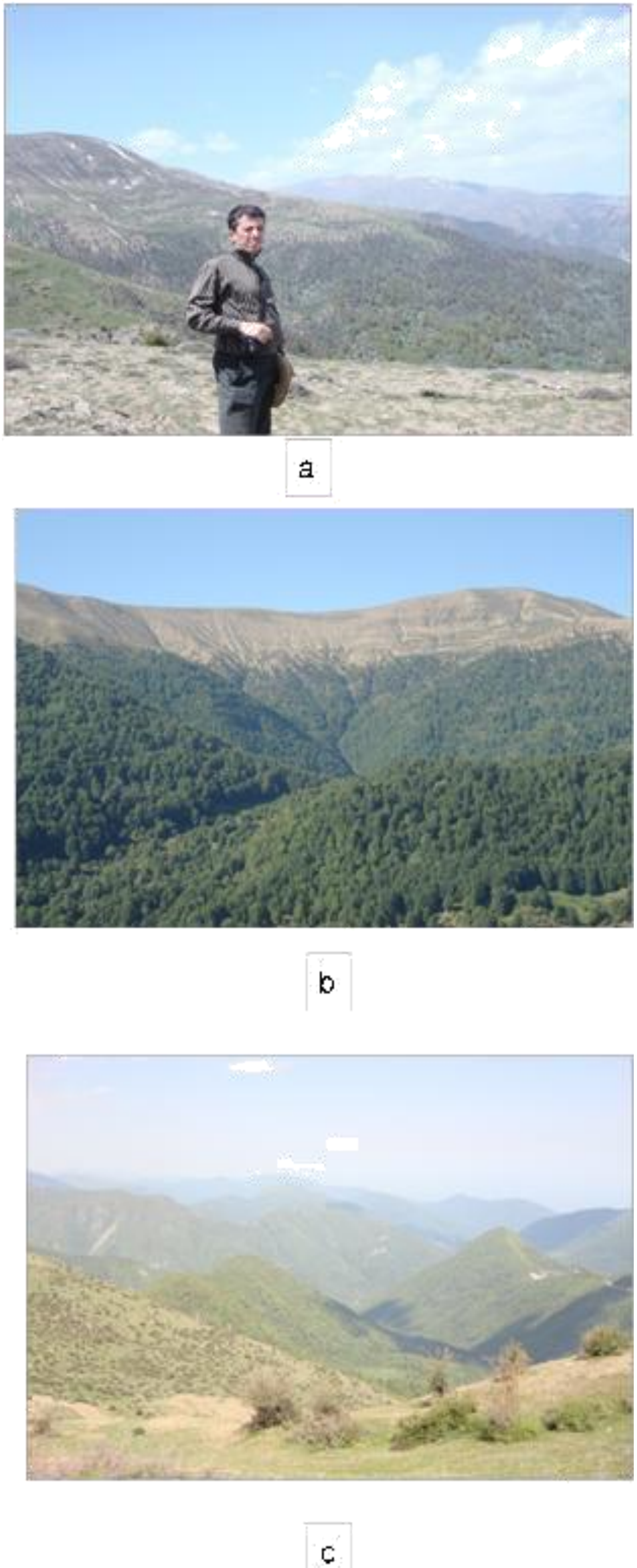

Figure 4. Treeline ecotone of the study area, (a) Western, (b) Middle and (c) Eastern parts (date: 18 Jul.2010).

expected given the offsets in the relationships between posterior probabilities and the quadrate data, which were compounded by calculating ratios.

Conclusion

Stereoscopic visual probability of class membership from a standard classification can enable a much more detailed characterisation of an upland treeline ecotone than a traditional classification. This probability of class membership for ‘scrub and forest’ was shown to relate to forest and shrub cover per pixel. However, this was not adequate to fully represent the upland treeline ecotone, since the transition was from closed-canopy forest to treeless rangeland and outspread vegetation. Therefore, an ecotone map had to consider the stereoscopic probability for ‘scrub and forest’ and for the non-forest vegetation classes of ‘pasture and natural grass’ and ‘sparse herbaceous vegetation’. However, the ratio values themselves did not relate very accurately to proportional vegetation cover. Ecotones are often ignored or misrepresented in thematic maps produced using remotely sensed imagery. Representing an ecotone from image classification requires thought on the part of the producer. A user working with thematic products from soft classification requires a greater understanding of the products and their method of production than with standard thematic maps. The question of how to derive spatial statistics on an ecological transition between two vegetation communities, being an ecotone, having no clearly defined spatial boundaries remains an issue that is to be addressed.

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