ISPRS Journal of Photogrammetry and Remote Sensing 75 (2013) 48–63

Contents lists available at SciVerse ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Super-resolution image analysis as a means of monitoring bracken (*Pteridium aquilinum*) distributions

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ARTICLE INFO

Article history:
Received 16 January 2012
Received in revised form 8 October 2012
Accepted 16 October 2012
Available online 5 December 2012

Keywords:
Bracken
Super-resolution
Classification
Monitoring
Vegetation
Scale

ABSTRACT

The bracken (*Pteridium aquilinum*) fern is environmentally significant due to its great abundance and swift colonisation, and its perception as a problem plant in degrading agricultural or ecologically sensitive land. Various attempts have been made to map bracken using remote sensing, but these have proved relatively unsuccessful, often apparently constrained by the lack of spatial detail associated with medium spatial resolution satellite sensors such as the Landsat series. In this study, bracken was characterised using a combination of 30 m Landsat sensor imagery and 4 m IKONOS imagery. Different classification techniques were compared, including hard maximum likelihood classification and a super-resolution approach comprising soft classification and sub-pixel contouring. These techniques were applied to a range of image dates, including summer, winter and multitemporal images. Image analysis was supported by extensive field data collection, comprising both a land cover survey and stakeholder interviews. For the hard classified Landsat sensor imagery, the summer image proved least able to characterise bracken, due largely to the spectral similarity between (green) growing bracken and grasses and other vegetation. The winter images were more successful for identifying bracken due to the strong contrast between dead (brown/red) bracken and other vegetation. However, the multitemporal Landsat image was considerably more accurate than any of the single date images. The hard classified IKONOS image was more accurate overall than the Landsat sensor images for classifying land cover. Surprisingly, though, it was not comprehensively more accurate for mapping the bracken class. Notably, the producers accuracy of bracken was lower for the IKONOS image than the Landsat sensor images. This suggests image spatial resolution, although influential on the success of bracken characterisation, is not necessarily the sole or main determinant of classification accuracy. Also important are the temporal nature of image acquisition (here the multitemporal Landsat sensor image proved of considerable benefit) and the spectral characteristics of the imagery (here IKONOS's four visible and near infrared spectral wavebands proved limited compared to the Landsat sensors' six visible, near and shortwave infrared bands). Following soft classification of the multitemporal Landsat image, super-resolution sub-pixel contouring was applied to identify the boundary of bracken patches. Predicted bracken boundaries were assessed against actual boundaries identified using field observation and IKONOS image interpretation. For comparison, the bracken boundaries identified through hard classification (i.e. using pixel edges) were also assessed against the actual boundaries. Overall, the spatial accuracy of the super-resolution approach proved considerably higher than that of hard classification.

1. Introduction

The bracken (*Pteridium aquilinum*) fern is considered "one of the world's most successful plants", able to cover extensive tracts of land, and native to all continents except Antarctica (Natural England, 2008b). While bracken does have certain ecological value, it is thought of as a weed in many parts of the world, due in part to its great abundance, swift colonisation and resilience to varying environmental conditions. There is some uncertainty and controversy about the value or otherwise of bracken, and the speed and extent with which it colonises new land (Marrs et al., 2000). Therefore, there is a clear need for effective monitoring of bracken distributions; and remote sensing offers the only practical means of achieving this over large areas (Blackburn and Pitman, 1999; Schneider and Fernando, 2010). This paper considers existing work in characterising bracken from remotely sensed images, and adopts

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0924-2716/$ - see front matter © 2012 International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS) Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.isprsjprs.2012.10.002

a new mapping approach to increase the accuracy and cost-effectiveness of bracken identification. Innovatively, this article seeks to explore the unrealised potential of medium spatial resolution imagery and novel super-resolution analysis for the important topic of semi-natural vegetation monitoring.

1.1. Bracken as a 'problem plant'

In the UK, bracken is a common and characteristic feature of many semi-natural areas (Stace, 1997), due to its large area of coverage and its distinct pattern of seasonal change. Bracken grows quickly throughout the spring and summer, exhibiting vigorous vegetation (green), and dies back in the autumn to form a thick mass of deep red/brown matter (Fig. 1). This dead matter persists throughout the winter and well into the spring of the next year, when it is replaced, or at least obscured, by new bracken growth. These winter colours are distinct, setting bracken apart from other vegetation types, and contributing to a stereotypical image of the British countryside, with hillsides covered by deep red and brown hues (Page, 2010).

Historically, bracken was harvested for a range of uses including compost, thatch, animal bedding and potash. However, the decline in these uses has meant it is no longer considered an important resource that needs to be conserved (Pakeman et al., 1996). Instead, bracken is often now considered a problem plant (Taylor, 1986), and there is little doubt that "bracken has spread since the 18th century, because areas then cultivated are now covered with Pteridium" (Rymer, 1976). Farmers dislike bracken for several reasons. Encroachment of bracken can reduce the amount, and quality, of land available for grazing (Birnie, 1985). Bracken itself can be poisonous to livestock, as well as being a host for sheep ticks that can cause tick-borne fever (Evans, 1986; Hannam, 1986). When animals become ill, it can be difficult to locate them in dense bracken patches, preventing or delaying treatment (Varvarigos and Lawton, 1991). Bracken removal is particularly difficult as the root structures penetrate deep underground. Spraying bracken with the chemical Asulam is one common control method, but this only removes bracken in the short term, with regrowth often apparent after around 3 years (Robinson, 2009). There is also some uncertainty about whether or not these chemicals harm other nearby plants or foraging animals (Birket, 2009; Standring, 2009).

Another significant concern about bracken is its potential encroachment into areas of high biological importance. For instance, it has been noted that moorland, lowland heathland (Pakeman and Marrs, 1992) and lowland acid grassland (Natural England, 2008a) are particularly vulnerable to bracken encroachment. "In conservation terms the loss of heather moorland through bracken invasion is viewed as disastrous" resulting in the loss of nesting sites for grouse and raptors, especially Merlin (Pakeman and Marrs, 1992). However, despite its perception as a problem plant, bracken does hold some ecological value, and the UK Government Biodiversity Action Plan identifies several priority species that rely on bracken habitat. Bracken habitat is "considered crucial for many populations of high brown and pearl-bordered fritillary" butterfly (Natural England, 2008a). Bracken also provides a nesting habitat for nightjar and skylark, is often used as a refuge from pre-

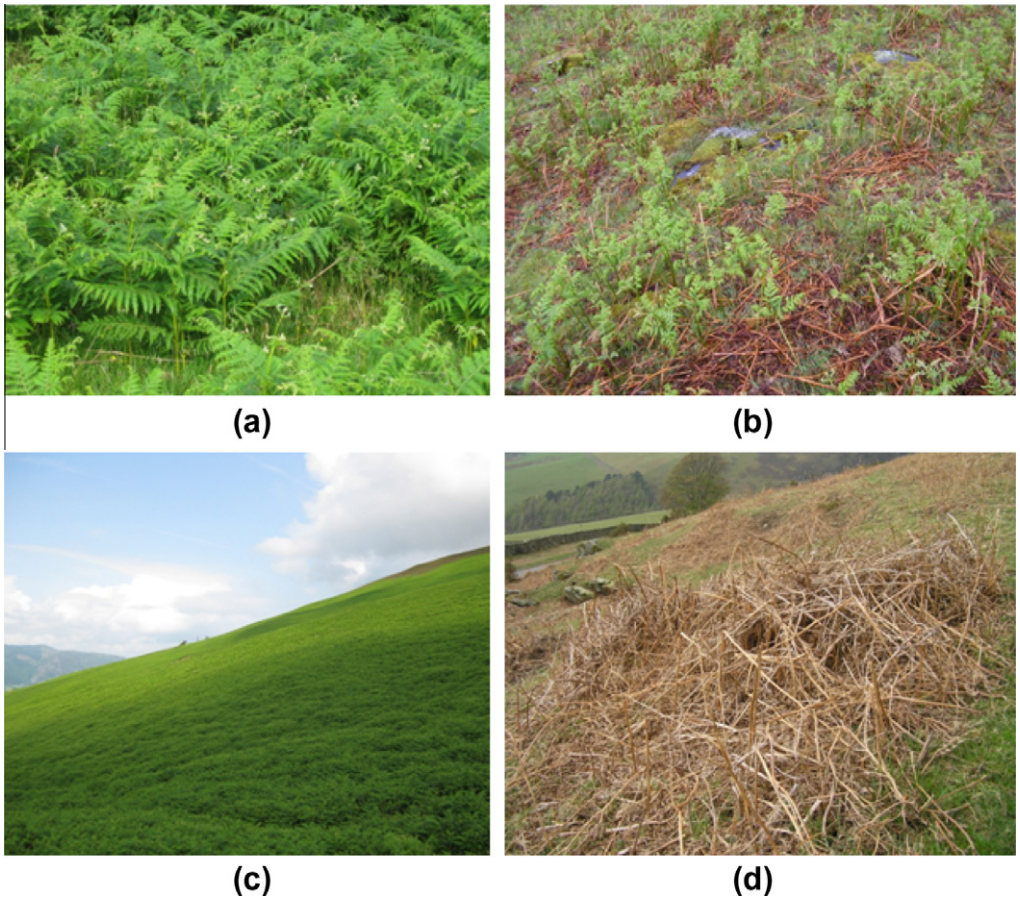

Fig. 1. Seasonal change in the appearance of bracken in the Blencathra study area, Lake District National Park, UK. (a) Bracken individuals in full growth. (b) Bracken landscape in spring. (c) Bracken landscape in summer. (d) Bracken landscape in winter.