International Journal of Applied Earth Observation and Geoinformation 44 (2016) 113–123

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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

Measuring and monitoring linear woody features in agricultural landscapes through earth observation data as an indicator of habitat availability

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ARTICLE INFO

Article history:
Received 30 June 2015
Received in revised form 24 July 2015
Accepted 26 July 2015
Available online 25 August 2015

Keywords:
Linear woody features
Hedgerows
Windbreaks
Landscape
Biodiversity
Indicators
Line intersect sampling
Earth observation
Monitoring

ABSTRACT

The loss of natural habitats and the loss of biological diversity is a global problem affecting all ecosystems including agricultural landscapes. Indicators of biodiversity can provide standardized measures that make it easier to compare and communicate changes to an ecosystem. In agricultural landscapes the amount and variety of available habitat is directly correlated with biodiversity levels. Linear woody features (LWF), including hedgerows, windbreaks, shelterbelts as well as woody shrubs along fields, roads and watercourses, play a vital role in supporting biodiversity as well as serving a wide variety of other purposes in the ecosystem. Earth observation can be used to quantify and monitor LWF across the landscape. While individual features can be manually mapped, this research focused on the development of methods using line intersect sampling (LIS) for estimating LWF as an indicator of habitat availability in agricultural landscapes. The methods are accurate, efficient, repeatable and provide robust results. Methods were tested over 9.5 Mha of agricultural landscape in the Canadian Mixedwood Plains ecozone. Approximately 97,000 km of LWF were estimated across this landscape with results useable both at a regional reporting scale, as well as mapped across space for use in wildlife habitat modelling or other landscape management research. The LIS approach developed here could be employed at a variety of scales in particular for large regions and could be adapted for use as a national scale indicator of habitat availability in heavily disturbed agricultural landscape.

1. Introduction

The conservation of wildlife and their associated habitats is becoming an issue of increasing concern around the world. The loss of natural habitats and the loss of biological diversity is a global problem affecting all ecosystems ranging from, for example, boreal forests (Wilcox and Murphy, 1985; Schmieglow and Monkkonem, 2002), marine environments (Worm et al., 2006) as well as agricultural landscapes (Burel et al., 1998). Monitoring human impacted ecosystems is essential in order to ensure their proper functioning is not impacted in terms of ecosystem processes, which is supported by ecosystem's biological diversity. The quantification and assessment of baseline conditions along with regular ecosystem monitoring can provide warning of undesirable changes and additionally provide a means for evaluating the success of various management strategies with respect to protecting biodiversity (Pereira and Cooper 2006; Cabello et al., 2012).

Many agricultural landscapes are heavily managed for cultivation. These landscapes are considered to be highly disturbed environments with very little natural or semi-natural landcover remaining amongst a matrix of heavily managed crop land, pasture and man-made structures. It is well established that the amount and variety of available habitat on agricultural landscapes is directly correlated with biodiversity levels (Fuller et al., 1997; Fahrig et al., 2011). Further, agricultural expansion, or land conversion, as well as intensification of agricultural practices is continuing to have negative impacts on wildlife attempting to inhabit agricultural landscapes, including as a result of habitat fragmentation (Fahrig, 2003; Fahrig et al., 2010). Within such heavily disturbed landscapes, remnant patches of natural and semi-natural landcover, including forest fragments, wetlands, riparian strips, abandoned agricultural fields, and field margins provide critical habitat to a wide variety of bird, mammal and invertebrate species that live within agricultural landscapes and as well as travel through them.

While perhaps not widely discussed in North American agricultural landscapes, linear woody features play a vital role in

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http://dx.doi.org/10.1016/j.jag.2015.07.008

supporting biodiversity. These features exist in a range of conditions from remnants of natural vegetation to planted and heavily managed features. Linear woody feature (LWF) is a general term which, depending on the geographic region and purpose, includes hedgerows, windbreaks, and shelterbelts. While it is difficult to assign a universal definition in terms of length, width and composition, for the purpose of this research, LWF refer to a line of trees and / or woody shrubs on an agricultural landscape between and along cropped fields as well as along roadways, lanes, rail corridors and watercourses. These linear features can be the remnants of predisturbance natural forest stands (Schmucki et al., 2002), the result of planting activities intended to mark property boundaries, keep livestock in or out of fields, as well as shelter agricultural fields from winds in order to prevent soil erosion and manage snow distribution. Additionally they are formed as the result of natural growth or regrowth in non-cultivated margins or field boarder areas (Burel 1996; Baudry et al., 2000).

Linear features have been recognized for the wide variety of essential ecosystem services which they provide. LWFs have been shown to help control and prevent runoff and flooding (Burel 1996), are a significant source of stored carbon (Huffman et al., 2015), support critical pollination services (Albrigo and Russ, 2002; Hannon and Sisk, 2009), and perhaps most importantly from the perspective of this research provide essential food, shelter and movement corridors for a wide variety of wildlife and enhance biodiversity across the landscape (Burel 1996; Davies and Pullin, 2007; Haenke et al., 2014; Jobin et al., 2014).

Field-based manual approaches have been and continue to be used to assess the overall length of hedgerows as well as detailed information on species composition and structure in some jurisdictions (UK Department for Environment, Food and Rural Affairs, 2007) however while potentially very accurate, this practice can be very resource demanding and requires an appropriate level of knowledge and skill to be conducted properly. Instead, LWF can be detected and mapped using a variety of approaches using aerial photography or high resolution satellite. Manual delineation of LWFs from imagery is possible, but similarly to field-based methods can be extremely labour intensive, especially across vast agricultural landscapes. Automated image classification approaches have been tested over small areas for detecting and mapping hedgerows and other linear woody features in agricultural landscapes. Such methods range from traditional reflectance based pixel clustering to multi data set object-based segmentation (e.g. Liknes et al., 2010; Aksoy et al., 2010; Pankiw and Piwowar, 2010; Atchison and Ghimire, 2012; Black et al., 2014). To date automated techniques have not generally been used beyond small local study areas and certainly have not been applied to large scale ecozone or ecoregion scale assessment.

Line intersect sampling (LIS), originally proposed by Canfield (1941), is one sampling approach commonly used for detecting and quantifying linear features on the landscape. LIS relies on intersections of sampling lines with the linear features of interest. While, LIS has historically been used for field-based vegetation surveys, more recently it has been adapted for use with remotely sensed images. For example, LIS has been applied for a variety of range of spatial distributed features including estimating the length of forestry roads (Matern 1964), agricultural crop residues (Laflen and Colvin, 1981), course woody debris (Van Wagner, 1964; Gregoire and Valentine, 2003) as well as forest edge and ecotone density (Corona et al., 2004; Esseen et al., 2006).

Under the UN Convention on Biological Diversity, participating countries have committed to developing and utilizing indicators to monitor and help prevent further loss in biodiversity as well as maintaining ecosystem integrity (United National Convention on Biological Diversity (UN-CBD), 1993). Indicators not only provide standardized measures that make it easier to compare and communicate changes to an ecosystem, but they can also provide indirect measures or correlates to variables or concepts, such as biodiversity, which are difficult, expensive, time consuming and often impossible to truly measure (Noss, 1999; Carignan and Villard, 2006).

The objectives of this research were to develop a rapid earth observation (EO) based method using line intersect sampling for quantifying and monitoring linear woody features in agricultural landscapes specifically as an indicator of habitat availability. The approach developed was tested and applied at a variety of scales including the full extent of a large Canadian ecozone, with the intention of future further application at a national scale. The intention of this research was not to detect and map individual landscape features, but rather provide a means for monitoring landscape units in terms of the density of linear woody features.

2. Materials and methods

While directly applicable to any farming region, for development and test purposes this study was restricted the Canadian Mixedwood Plains ecozone which spans the southern regions of the provinces of Ontario and Quebec (Agriculture and Agri-Food Canada (AAFC), 2015). EO based methods for quantifying linear woody features were developed and tested at various scales using various test sub-regions, before being applied to the entire ecozone. Fig. 1 provides an overview of the development of methodology and mapping application of LIS for detecting and estimating LWF. All GIS processing and data collection was carried out within ArcGIS 10.2 (ESRI, 2015).

2.1. Study Area

The Mixedwood plains geographic location, fertile soils, relatively warm growing season and abundant rainfall have made it Canada's most intensively managed and densely populated region. This region is home to over 52% of Canada's population in 0.86 Mha of urban area with 41% of the total ecozone land area occupied by cropland (composed of annual, perennial and forage cropping areas) (Statistics Canada, 2011) (Table 1). In pre-European colonization times the region was heavily forested supporting more species of trees than any other region of Canada, however, currently less than 10% of the original tree cover remains including many rare and endangered tree species (Ecological Stratification Working Group, 1996; Government of Canada, 2015). In terms of the total Canadian agricultural extent, the ecozone provides almost 13% of Canada's cropland area.

In Canada, ecozones are further divided to reflect variation in soils and climate resulting in ecoregions that are characterized by distinctive regional landforms, macro- or mesoclimates, vegetation, soils, water, and regional human activity patterns and uses (Ecological Stratification Working Group, 1996). The Mixedwood Plains ecozone is composed of four ecoregions; Lake Erie Lowlands, Manitoulin-Lake Simcoe, Frontenac Axis and the St. Lawrence Lowlands. For the purpose of this work, the St. Lawrence Lowlands ecoregion was sub-divided into two regions split by the provinces of Quebec and Ontario (Fig. 2).

2.2. Sampling design and methods development

Line intersect sampling is a relatively easy approach used for assessing and estimating the density of discrete landscape elements particularly linear elements (Canfield 1941; Matern 1964). The approach is based on the "needle problem" in which one attempts to calculate the probability of a needle intersecting parallel lines when dropped randomly (Buffon 1777; Barbiere 1860). Matern (1964) provided a more detailed discussion of the theoretical basis which is