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Historical land cover assessment: challenges and achievements

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Abstract
This study aimed to develop a method for assessing changes in vegetation greenness and land cover over time at both landscape scales and for individual land parcels. It is hoped that an improved understanding of land cover history will increase understanding of soil condition, and linkages between soil health and productive capacity in Victorian agricultural landscapes. Gradual changes and differences in vegetation biomass can occur due to climatic and geomorphological factors. Sharper transitions in vegetation biomass coincident with cadastral boundaries and paddock fences also occur as a result of management history. Understanding the earlier land use history with respect to these parcels may reveal causal factors with respect to cover growth (e.g. extended fallow periods) that would explain, in part, the reasons for differences in current land productivity. This study utilised the historical Landsat archive to produce land cover and vegetation greenness information over a 38 year period in a localised area of the Wimmera region of Victoria. Data generated by this project will support efforts to examine the influences of farming systems on productivity and soil resources over time frames equivalent to soil change. The likely causes for local differentiation could include seasonal climatic variability, crop/soil management practices or local soil constraints.

This paper presents some preliminary findings in this ongoing study. The work presented here focussed on creating land cover and production histories for the study area and selected paddocks from satellite imagery. The project made use of the USGS Landsat archive that yielded 54 images from July 1973 to November 2011, which were largely clear of cloud cover. For each image, Normalised Difference Vegetation Index (NDVI) was calculated and a land cover classification using spectral signatures was generated. These data were interpreted in a number of ways. A time series of NDVI values for paddocks of interest was created, which showed varied patterns between paddocks. Cumulative NDVI across the landscape was also calculated which revealed distinct paddock boundaries as a result of land management history. These data also revealed a north-south transition across the study area from mostly low NDVI to mostly high NDVI, which is likely the result of climatic and soil property variation. Analysis of land cover also allowed land management history to be interpreted in terms of crop rotation and paddock fallow duration. The results so far provide clear evidence that the influence of long term management practices on productivity (vegetation cover) can be mapped using satellite imagery.

Keywords: Landsat archive, Land cover, NDVI, MESMA

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Introduction
Land cover describes the surface of the earth; whether it is rock, water, buildings or vegetation. Current land cover data available for the study area provides information for regional plans, modelling plant water use and emergency management of natural disasters such as fires and floods. Historically, land cover information has been collected for various projects or purposes with no consistent approach or reason and therefore historic land cover data is of little use if it is at all accessible. Land cover type can be classified in many different ways and the method and terminology is usually dependant on the purpose for which the land cover data will be used.

Mapping historic land cover types across a region is now possible using the Landsat satellite archive as the base imagery for interpretation. Without the archive, broad scale mapping across long time frames would not be possible and limited to smaller areas with less temporal frequency. Current advancements in processing of the Landsat image archive has led to a reliably calibrated data set, with a consistent absolute radiometric scale between sensors, spanning nearly 40 years, with total uncertainties of under 10% for most sensors and bands (Markham and Helder, 2012). These improvements to radiometric and geometric calibration have enabled use of Landsat data in multi-temporal studies spanning the life of the archive using data from different Landsat sensors (Hansen and Loveland, 2012). The availability of the Landsat archive is this form, and free of charge, has provided research scientists with unprecedented opportunities for land cover mapping and monitoring (Wulder et al., 2012).

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Further negotiations to ensure the continuity and availability of imagery from future Landsat missions will further enhance this important dataset (Loveland and Dwyer, 2012).

While there are many examples of land cover mapping exercises that use Landsat imagery within a limited time frame (Vogelmann et al., 1998; Oetter et al., 2000; Ward et al., 2000; Apan et al., 2002), there are fewer examples of work incorporating greater portions of the Landsat archive. Recently published studies that incorporate much of the archive include; Vogelmann et al (2012) who used 20 years of imagery to assess gradual changes in vegetation cover, Pflumacher et al (2012) who used data from 1972 to 2010 to assess forest disturbance history, Brinkman et al (2011) who used 23 years of data to assess changes in biomass, and Powell et al (2008) who used data from 1972 to 2006 to look at land cover changes. Time series analysis is important as it provides an improved representation of patterns and trends (Vogelmann et al., 2012). Access to 40 years of historical imagery is also producing more data intensive approaches to image analysis, which creates a range of data management issues (Hansen and Loveland, 2012).

This study aimed to develop a method for assessing changes in vegetation greenness and land cover over time at both landscape scales and for individual paddocks. It is hoped that an improved understanding of paddock land cover history will increase understanding of soil condition, and linkages between soil health and productive capacity in Victorian agricultural landscapes. It is assumed that differences in vegetation biomass will occur due to climatic conditions, soil properties and geomorphological factors, which will occur as gradations across the landscape, and also as a result of land cover and management history, which will occur as sharp transitions aligning with the cadastral boundary and land parcels (Hill and Donald, 2003; Sumfleth and Duttmann, 2008; Mänd et al., 2010; Wen et al., 2012). Understanding the earlier land use history with respect to these parcels may reveal causal factors with respect to cover growth (e.g. extended fallow periods) that would explain, in part, the reasons for differences in current land productivity (Hill and Donald, 2003; Dang et al., 2011).

Improved knowledge of historical land use not only improves our ability to manage the legacy of this history but also provides an insight into, or confirmation of, the likely impacts of current and future land use on soil health. Research in this area has improved our knowledge of linkages between data derived from remotely sensed imagery and agricultural information such as crop rotation, productivity, soil properties and management practices (Hill and Donald, 2003; Sumfleth and Duttmann, 2008; Dang et al., 2011). The development of land use history scenarios for this region will provide contextual information for the interpretation of differences in soil condition and agricultural production over the long term. This paper details the approaches taken towards image analysis, which will provide a basis for exploring the complex linkages between remotely derived indices and on-ground land, soil and crop properties in the future.

Methods

Study area

The study area was located in the Wimmera region of Victoria (Fig. 1), where 29 soil sample sites, used by the Department of Primary Industries, are located. These soil sites were tested for a range of soil properties between 1968 and 1972 (under the National Soil Fertility Program), again in 1992, and were recently resampled for a third time in 2011 and 2012. While methodologies used have varied over time, soil testing is conducted to characterise a selected paddock, using a series of samples at varying soil depths. Information from the landholder concerning historical land use and management practices of the paddock are also collected to create a comprehensive understanding of each individual paddock in terms of production and soil. The paddocks where these soil testing sites are located are of interest in this study, as future work aims to test relationships between land cover trends, land management practices and soil properties. The land cover history developed from Landsat imagery, presented in this paper, will provide context for understanding any changes in soil properties over the past 40 years. The wider landscape surrounding these paddocks was also analysed. The study area is dominated by rain-fed cropping production systems, pasture and grasslands, with remnant woody native vegetation found in small blocks and along watercourses. The land cover types classified here are focused on the production landscape and particularly broad crop types such as cereal, oilseeds and legumes.

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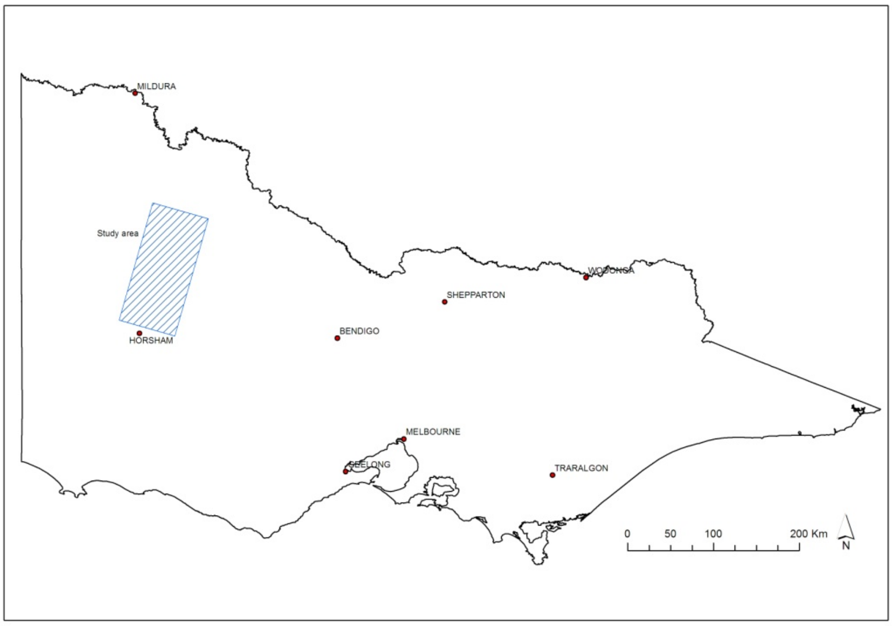

Figure 1. Location of the study area in the Wimmera region of Victoria

Image acquisition and processing

This study aimed to develop a method for assessing changes in vegetation greenness and land cover over time at both landscape scales and for individual paddocks using remotely sensed data. This project makes use of the USGS Landsat archive, which provides Landsat imagery to download at no cost (http://earthexplorer.usgs.gov.au/). The choice of Landsat imagery was based on the availability of historical imagery, it is freely available, and the spatial resolution of the imagery, which is appropriate for this work. Apart from being one of the longest series of imaging satellites, the Landsat series is unique because the scene size (approximately 170km x 180km) is large enough to work across landscapes, the spatial resolution (approximately 60m or 30m depending on the satellite used) is small enough to identify anthropogenic land cover change and all instruments have been fully calibrated to allow for monitoring of land cover change since 1972. Current advancements in processing of the Landsat image archive has led to a reliably calibrated data set, with a consistent absolute radiometric scale between sensors, spanning nearly 40 years, with total uncertainties of under 10% for most sensors and bands (Hansen and Loveland, 2012; Markham and Helder, 2012). The main exception to this is band 4 of the MSS sensor series, with absolute radiometric calibration uncertainties for this band reaching 25% in some instances due to the broad spectral bandwidth and atmospheric absorption features (Markham and Helder, 2012).

Several factors including image availability through the USGS, data quality (such as band striping), and cloud cover affected the final selection of images to use for this study. All data used in this study were downloaded in 2012 to take advantage of the most recent calibration processing applied by the USGS. Fifty-four images were used in this study, acquired between July 1973 and November 2011. Where possible, one image per season (four per year) was included to build annual paddock profiles and capture growing seasons of various crops. Each image was downloaded from the USGS archive and bands were converted to radiance and top of atmosphere reflectance using coefficients published in Chander et al (2009). Most data were processed to the L1T level by the USGS but some images required further geo-rectification, which was performed as necessary. To create a consistent spatial resolution across the time series, all images were resampled to a 30m spatial resolution. From these base images, NDVI and a land cover classification was produced.

NDVI was derived using red and near-infrared (NIR) reflectance:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}$$

where NIR = near infrared reflectance
Red = red reflectance

Using these NDVI images, paddock statistics (mean, minimum and maximum) were extracted to create a time series for each paddock. Each paddock had previously been spatially delineated and stored as a shapefile. These paddock profiles were also

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merged to create a time series of all paddocks, which represents an overview of agricultural production in the region. In addition to individual paddock analysis, the NDVI images were added together to create an NDVI sum total product for the period from 1973 to 2011. This analysis was conducted on a pixel-wise basis.

A Multiple Endmember Spectral Mixing Analysis (MESMA) image analysis approach was used to derive land cover classifications from Landsat imagery. This approach was used to replace land cover information sourced from land holders, which is unavailable at this time. However, when land holder information does become available it can be used as an independent source of validation. The spatial location of land cover types of interest were defined based on ground data collected for the Victorian Land Use Information System (VLUIS) (Morse-McNabb, 2011), which produces an annual Victoria-wide land cover classification produced from MODIS imagery. Images used to define these regions of interest were chosen based on time of acquisition in relation to ground data collection (approximately November 2009) and absence of clouds. A number of images were chosen to ensure all dominant land cover classes featured in the VLUIS land cover data set were accounted for in the training set used for the MESMA analysis.

Using the VIPER tools plug-in for ENVI (Roberts et al., 2007), a spectral library and the required metadata was created. Spectral signatures were based on the VLUIS dominant land cover classification that consists of 12 cover types; bare ground and non-photosynthetic vegetation, brassica, cereal, deciduous woody horticulture, evergreen woody horticulture, hardwood plantation, legume, native woody cover, non-woody horticulture, pasture and grasslands, softwood plantation and water. An additional class of impervious surfaces was added for this analysis. A pixel-wise land cover classification was produced initially. A dominant land cover was assign to each paddock based on the amount of coverage of different land cover classes within each paddock.

VIPER tools were then used to generate a square array and calculate statistics to assist in selecting appropriate spectral signatures to use for further classification. The 'View EMC File tool' in VIPER tools was used to select spectra for classification of the images. One set of signatures was selected and used to classify all the images used in the historical land cover classification. The 'SMA/MESMA model' (Spectral Mixture Analysis/Multiple Endmember Spectral Mixture Analysis) tool in VIPER tools was run using the single spectral library, cover fraction constraints at -0.05 and 1.05, a maximum shade fraction at 0.8 and maximum allowable RMSE 0.025.

Results

The results presented in this section constitute preliminary findings in this ongoing study. While trends within the selected paddocks were of interest in the study to enable linkages between remotely sensed data and soils information to be established in future work, analysis of trends across the broader landscape were also undertaken. The sum of NDVI across the landscape (using all 54 images available) is shown in Fig. 2. The total range in NDVI is 0.42 to 32, and the study area mean is 13.2. Very small sum NDVI totals are due to variations in the image scene extent over time, striping in some images and intermittent cloud cover in some images, which resulted in only one or two valid values for some pixels. Fig. 2 shows the centre of the study area where these issues are limited and therefore gives a good representation of the variation in vegetation production over time. Fig. 2 shows a north-south transition from mostly low to mostly high summed NDVI, however across all areas there are obvious paddock boundaries where there are distinct changes from low to high summed NDVI.

The average NDVI value for each of the 29 paddocks for all image dates was calculated. Analysis of NDVI values shows that 12 paddocks increase in green vegetation cover, 12 paddocks decreased in vegetation cover, and five showed steady green vegetation cover levels over the 38 years. A time series of the minimum, maximum and mean of the 29 NSFP sites is shown in Fig. 3. The first of the 54 images in the time series is July 1973 and the last from November 2011. Not all years have representative images. Fig. 3 shows instances when the minimum, maximum and mean have very similar values (shown in red ovals). All of these images were acquired from January, February or March when dry, hot climatic conditions dominated and all NDVI values (minimum, maximum and mean) fall under 0.2. There are five other instances where the maximum NDVI is greater than 0.2 but the mean value is less than 0.2 (highlighted in green ovals).

The MESMA approach was used to classify land cover types from 2000 to 2011. The approach taken replaces the need for land cover histories supplied by landholders at this stage, but the absence of appropriate ground data means the results cannot be validated at this point in time. MESMA land cover class groupings were evident when plotted against the mean NDVI for each paddock in each growing season from 2000 to 2011, as shown in Fig. 4. Land cover classes with low or no vegetation clearly fall below 0.3 NDVI mean values. Cereals consistently showed high NDVI values of greater than 0.6. As all paddocks were agricultural paddocks, some miss-classification between crops and woody horticulture is evident. Using the time series data available, the frequency of cropping and fallow cycles can be derived. Fig. 5 shows the frequency of cereal crops recorded from spring images during the period from 2000 to 2011.

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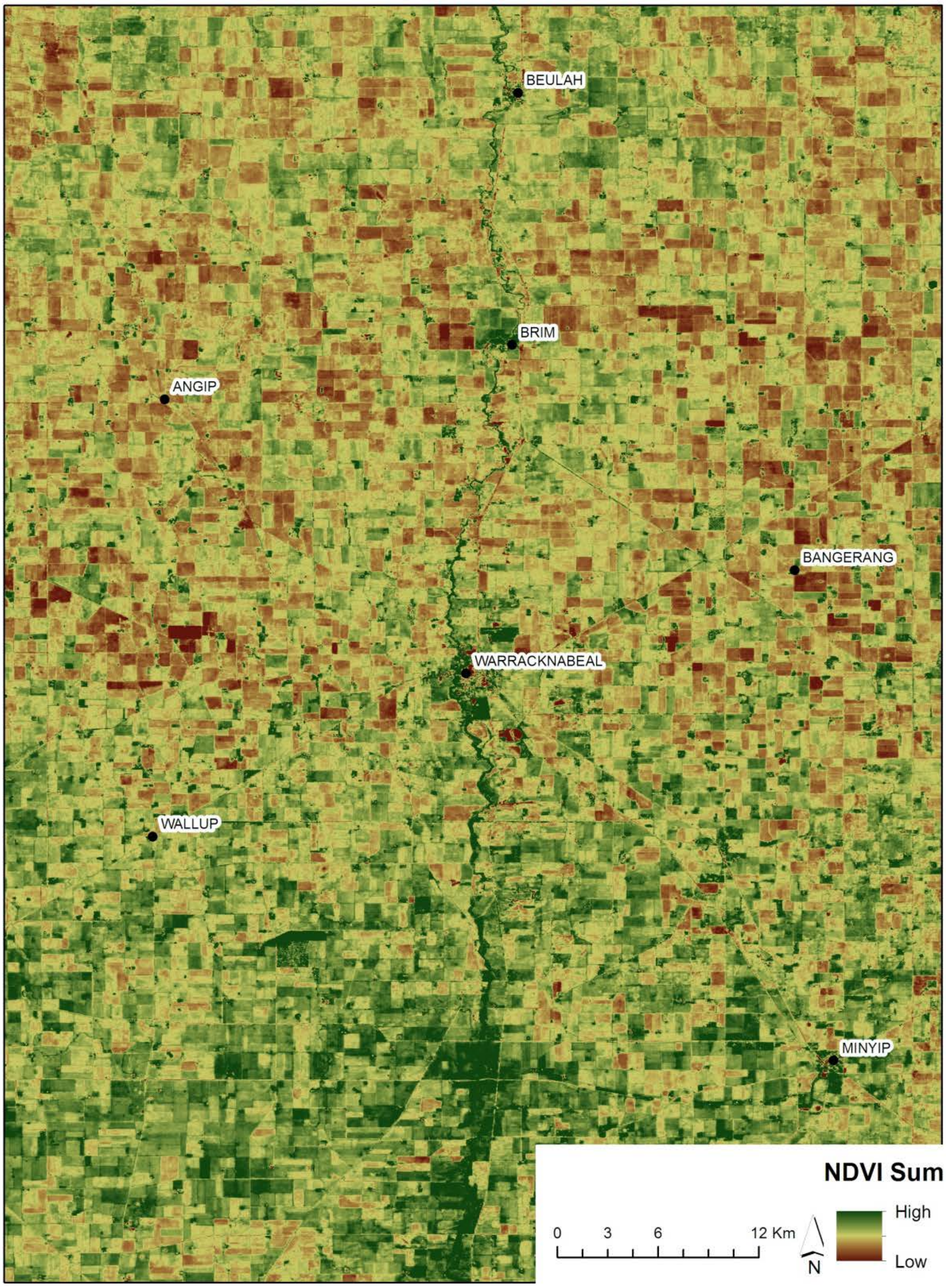

Figure 2. Sum of NDVI values for the study area using all 54 images analysed form 1973 to 2011

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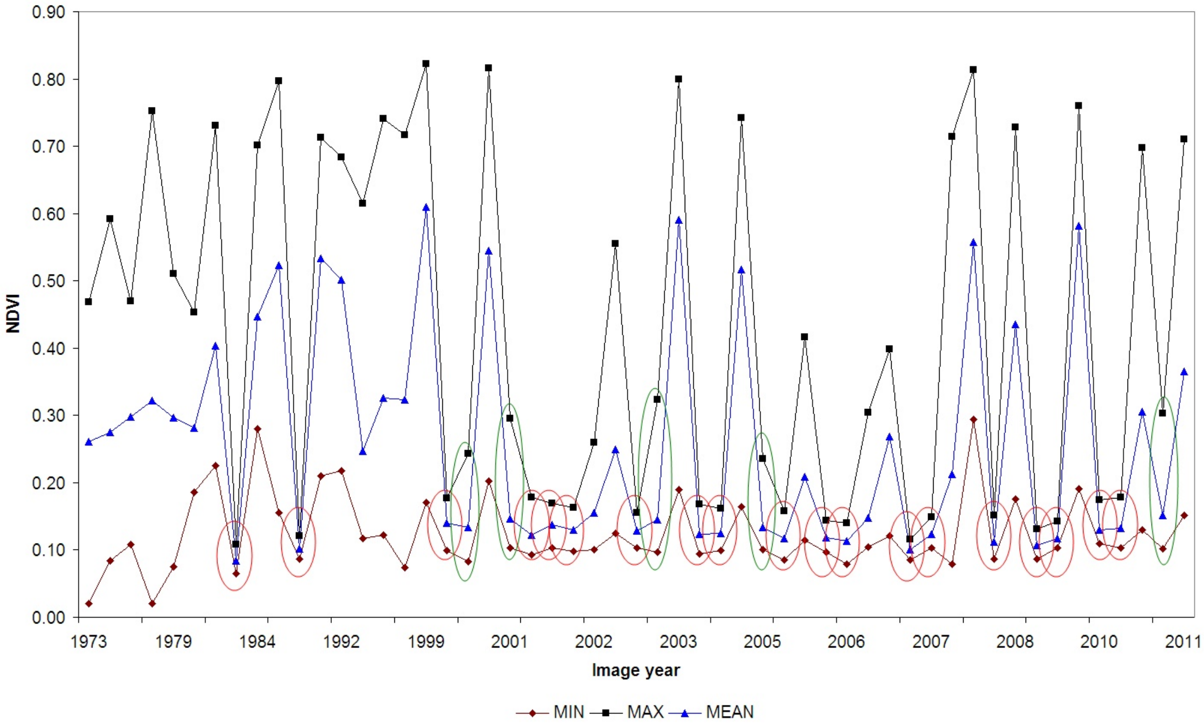

Figure 3. A time series of minimum, maximum, and mean NDVI values for all selected paddocks, from 1973-2011. Image dates with similar values are shown in red ovals. Image dates where the maximum NDVI is greater than 0.2, but the mean was less than 0.2 are highlighted in green ovals.

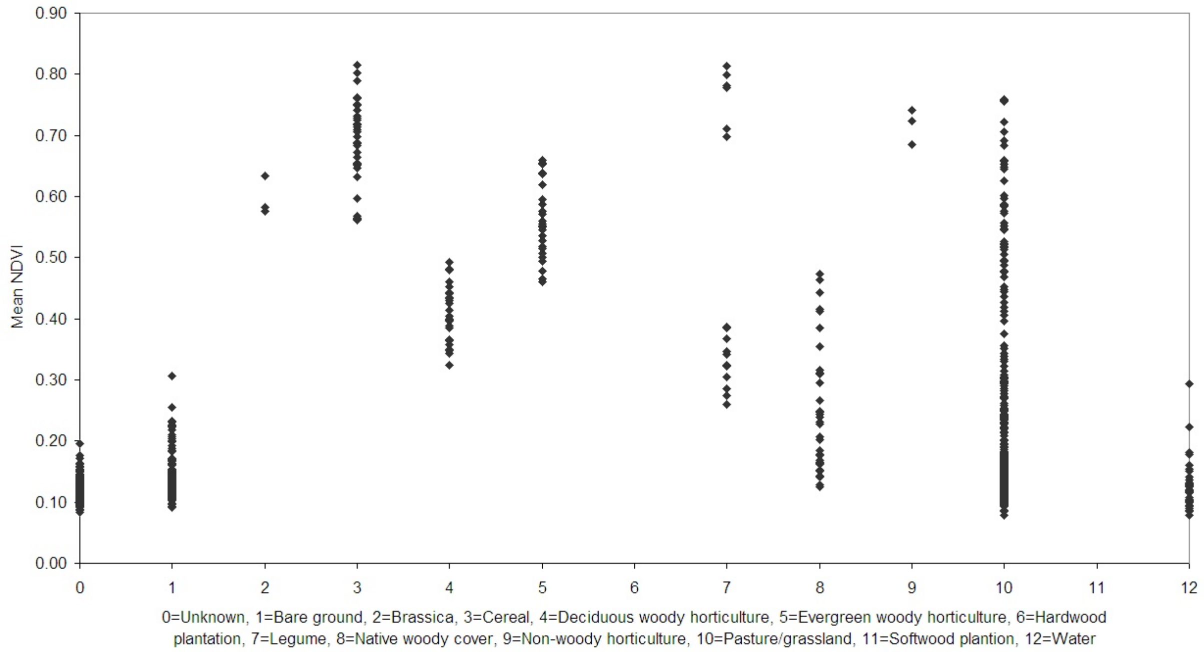

Figure 4. Mean NDVI grouped by land cover for all selected paddocks from 2000-2011

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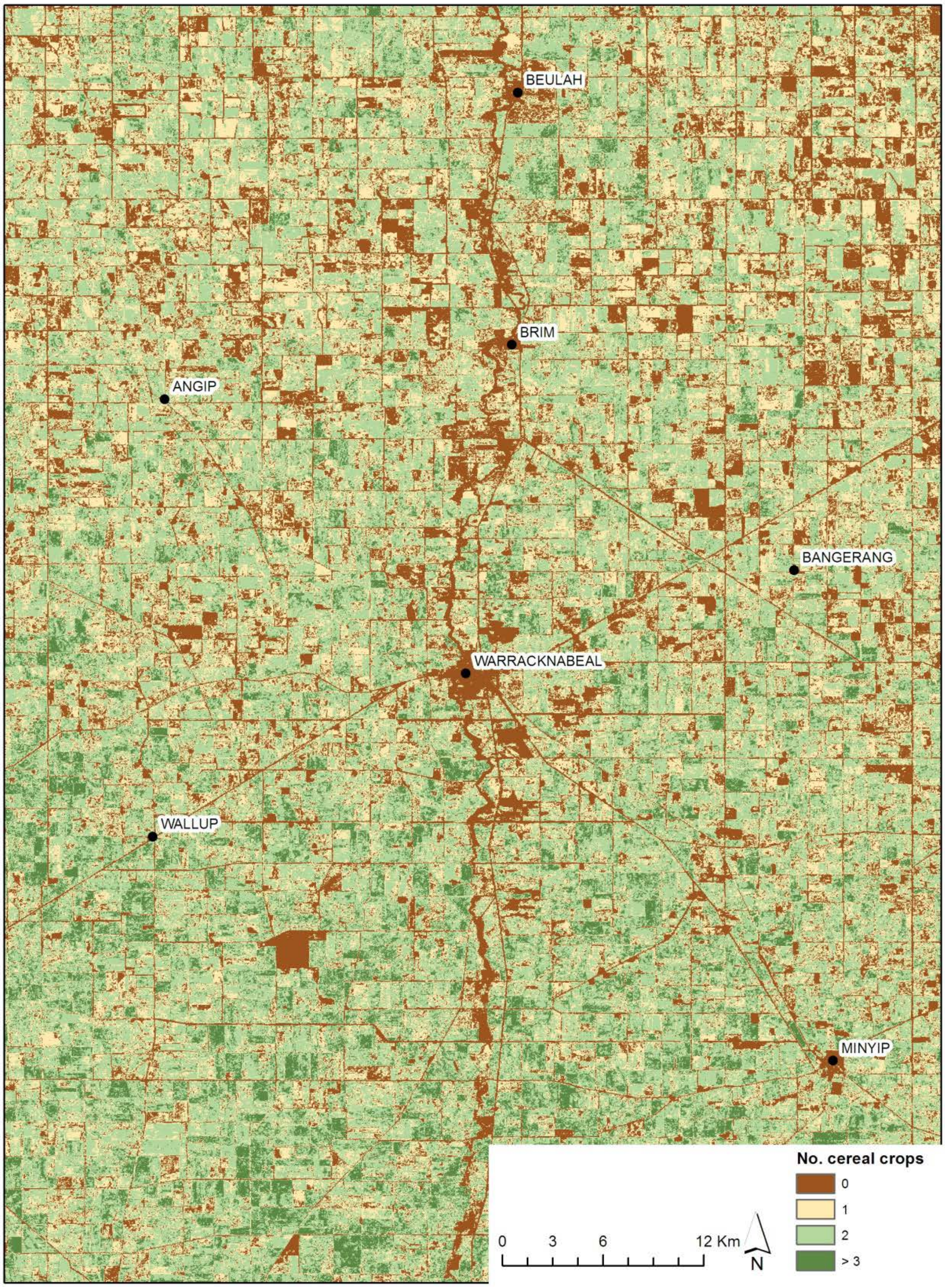

Figure 5. Number of cereal crops (classified using the MESMA approach) recorded from 2000 to 2011

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Discussion

Mapping historic land cover types across a region is now possible using the Landsat satellite archive as the base imagery for interpretation. The advancements in processing of the Landsat image archive has led to a consistently calibrated data set, with a consistent absolute radiometric scale between sensors (Markham and Helder, 2012). These improvements to radiometric and geometric calibration have enabled use of Landsat data in multi-temporal studies spanning the life of the archive using data from different Landsat sensors (Hansen and Loveland, 2012). The availability of the Landsat archive in this form, and free of charge, has provided research scientists with unprecedented opportunities for land cover mapping and monitoring (Wulder et al., 2012).

This study aimed to develop a method for assessing changes in vegetation greenness and land cover over time at both landscape scales and for individual paddocks. To achieve this, NDVI and land cover were derived from Landsat imagery spanning nearly 40 years. This study also focussed on agricultural land cover types, including agricultural crop types rather than differentiating changes in woody vegetation cover, which is the focus of many existing studies (Hansen and Loveland, 2012).

NDVI provided a large amount of information regarding trends over time in terms of vegetation greenness and relative production, while land cover information provided insights into land management history. The variation of NDVI across the landscape was mapped, as shown in Fig. 1. This information shows the variability of green vegetation, and vegetation production, within a region. The spatial distribution of this information can assist in determining both natural and anthropogenic causes for the variability observed. A north-south transition occurs from mostly low to mostly high summed NDVI, however across all areas there are obvious paddock boundaries where there are distinct changes from low to high summed NDVI. These sharp transitions can be assumed to result from land management activities, rather than soil or climatic variables. In addition, land parcels with similar characteristics can be identified allowing greater insight into production history and the impacts of management to be established.

A time series of NDVI for paddocks was also compiled (Fig 2). This information can identify crop and fallow rotations for individual paddocks and identify general regional trends. It provides insight into production, in terms of vegetation greenness or crop cover, over an extended period of time. Average NDVI values for paddocks were also analysed in terms of land cover (Fig 3). Aggregating information in this way is a useful tool for discriminating trends within land cover classes. The range of NDVI values for given land covers could, potentially, improve the discrimination between land cover classes in future applications. The information was also used to investigate cereal cropping intensity, as shown in Fig 4. Information on frequency of cereal crop plantings is indicative of past management of land parcels and can be used, in conjunction with information of productivity (vegetation greenness) and soil health to assess land condition. The spatial representation of the data allows land parcels with similar histories to be identified and the impacts of management on productivity to be assessed.

The imagery used in this study was limited to data accessible through the USGS. Currently, there are data gaps through the 1980’s and 1990’s, however systems to supplement the online archive with data held by in international archives, including Australia (Loveland and Dwyer, 2012) should improve this situation. To supplement the currently available Landsat image archive, there is a potential to use MODIS imagery from the last decade to compare with Landsat imagery, in terms of land cover classification and NDVI. While the spatial resolution of the MODIS imagery is substantially coarser than the Landsat imagery, the improved temporal resolution of MODIS imagery improves our ability to target key dates in terms of crop production, which will improve our understanding of land cover type, crop classification and land production. This also presents an opportunity to refine the land cover classification scheme, which will also be improved by the addition of historical ground information, which should become available within the next year.

The results so far provide clear evidence that the influence of long term management practices on productivity (vegetation cover) can be mapped using satellite imagery. With the addition of land cover and management histories for NSFP sites, collected from landholders, and soil health information collected during the past 40 years for selected paddocks, this data suite should provide a solid foundation to generate an improved understanding of the linkages between soil health, land cover history and agricultural production in the Wimmera.

Conclusion

This work aimed to improve understanding of paddock land cover history with an objective to increase understanding of soil condition, and linkages between soil health and productive capacity in Victorian agricultural landscapes. Gradual changes and differences in vegetation biomass can occur due to climatic and geomorphological factors. Sharper transitions in vegetation biomass coincident with cadastral boundaries and paddock fences also occur as a result of management history. Understanding the earlier land use history with respect to these parcels may reveal causal factors with respect to land cover (e.g. extended fallow periods) that would explain in part the reasons for differences in current land productivity. The use of satellite imagery will enable the relationships and trends established with paddock based information, such as detailed soil analysis and land management histories, to be generalised across the landscape. This approach will save on investment in ground data collection by enabling prior targeting of areas. Improved knowledge of historical land use not only improves our ability to manage the legacy of this

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history but also provides an insight into, or confirmation of, the likely impacts of current and future land use on soil health. The development of land use history scenarios will provide contextual information for the interpretation of differences in soil condition and agricultural production over the long term. The results so far provide clear evidence that the influence of long term management practices on productivity (vegetation cover) can be mapped using satellite imagery.

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