Chapter 1 Introduction

The purpose of the research outlined in this thesis was to explore the potential of a range of remote sensing and modeling techniques to assist in the investigation of suitability of land cover mapping. The investigations focused specifically on the influence of the length of time between images, alternative methods and season on long-term land cover change in north-eastern New South Wales (NSW), Australia. The research mostly focused on determining the best techniques for land cover change detection in the region through developing new methods or modifying existing techniques. The research summarizes land cover pattern change over a 37-year period (1972–2009), and projects the land cover change over the next 10 years (i.e. to 2019). The patterns in land cover change were assessed and quantified in terms of changes in wildlife habitat over the study period in order to understand the changes in the extent and configuration of native vegetation.

This introductory chapter outlines the statement of problem, defines land use and land cover, review the general approach to land cover mapping and change identification, summarizes the issues associated with landscape pattern metrics analysis, land cover transition modeling and change predictions, and considers the utility of terrestrial habitat monitoring for measuring the impact of land cover change on biodiversity. It then goes on to describe the remote sensing, geographical information system (GIS) and land cover modeling systems employed in this research, along with their potential benefits for mapping, monitoring and change identification using large datasets. The chapter concludes with the specific aims of the research and an outline of the structure of the thesis.

1.1 Definition of problem

Even though the two terms land cover and land use, are often used interchangeably, they are different as land cover is anything present on earth surface such as forest, cropland, grass, etc., whereas land use refers to the purpose for which human manage or utilize covers (Turner, 1994). However, they are dependent on each other as land cover change causes land use change and vice versa. The factors governing land use and land cover include (a) economic – development and modification of land for crop production and infrastructure development or urbanization, (b) technological – advancement in industrialization, (c) demographic – increasing population and hence more demand for land for food and fodder, and (d) landscape beautification – development of parks and other recreational centres. Hence, land use and land cover dynamics are a result of complex interactions between several biophysical (Reid et al., 2000), physiographic and socio-economic influences (Turner et al., 1994; Forman, 1995), which occur at various temporal and spatial scales (Pan et al., 1999; Reid et al., 2000; Jenerette et al., 2001).

Because of anthropogenic transformation and modification, land cover has undergone continuous change for centuries as human production demands cannot be fulfilled without modification and conversion of land cover (Vitousek, 1994). In the past two centuries, the impact of human activities on land has grown enormously because of population increase (Jenerette et al., 2001), technological development and the requirements thereof, altering entire regional ecosystems (Houghton, 1994; Lambin, 1997). These changes ultimately affect and change biodiversity (Fahrig and Merium, 1985; Wu et al., 1993; Dale et al., 1994b; With and Crist, 1995, Xiuwan, 2002; Falcucci et al., 2007), nutrient and hydrological cycles (Peterjohn and Corell, 1984; Hobbs, 1993) as well as the global environment (Turner et al., 1994; Reid et al., 2000; Xiuwan, 2002) and climate (de Sherbinin, 2002).

Biodiversity is the variety of life in a given area. It improves the quality of people's lives and is essential for humans for food, shelter and health (DECC, 2008). It also provides drinkable water, clean air and fertile soils in the form of indirect services. Various anthropogenic activities can upset the normal functioning of biodiversity and disrupt ecological services, resulting in threats to biodiversity in the form of habitat destruction, modification in ecosystem composition, introduction of exotic (non-native) species, over-exploitation, pollution and climate change (DECC, 2008).

The nature and extent of land use change may not be directly associated with landscape health, but it provides an important understanding of the process that leads to land degradation. Land use change can also serve as a surrogate for landscape condition, particularly land capability information and land-management practices formulate land use as an indicator of landscape and soil health (NLWRA 2005). Ecosystem services provided by healthy soils support agricultural land productivity and also form the basis for landscape health. Extensive landscape modification to various activities related to agriculture use, urban and infrastructure developments has led to a decline in landscape health by putting severe stress on soils, water and vegetation (Lockwood et al., 2003).

1.2 Distribution of major land use types in NSW

Land use in NSW is dominated by agriculture, accounting for 76% of the state's total land area. The most extensive land use in the state is grazing (69.8%), followed by cropping (7.9%), forestry (3.6%) and mining (0.1%), with irrigation and other intensive uses accounting for less than 1% (NSW SOE, 2006). Conservation lands occupy 7.8% of the total area, while urban development is less than 0.2% (NSW SOE, 2006).

Time-series data are required to determine land use trends. However, accurate assessment of land use change for a given period is difficult due to the inconsistencies in existing data sets and delay in data collection and publications (NSW SOE, 2006). According to NSW SOE (2006), land use trends evident over the past few decades include:

- Change of some of the state forest estates to the conservation estate.
- continuing urban growth, particularly in western Sydney and along the coast
- more-intensive agricultural practices – for example, a change from dryland cropping to irrigation cropping and horticulture

Irrigation has been a major driver of land use change in NSW. The area used for irrigation increased nationally by 26% in the 15 years from 1981–82 to 1996–97 with most of this increase occurring in NSW (Walcott et al., 1999). Other recent developments, including breakthroughs in crop genetics, advances in pest and weed control and emerging technologies such as precision and alley farming, have provided opportunities to expand and change land uses (SOE, 2006).

1.3 Native vegetation – biodiversity

NSW has a great variety of native vegetation including rainforests, alpine zones, wetlands, grasslands and eucalypt forests and woodlands, reflecting the diversity of species, habitats and ecosystems found across the State (SOE, 2006).

Native vegetation provides essential habitat for many plant and animal species, and is an integral component of healthy, functioning ecosystems and an important indicator of ecosystem diversity (Saunders et al. 1998). Since European settlement, extensive clearing of native vegetation have occurred for various activities, a phenomenon which is generally irreversible due to subsequent land uses. It leads to habitat degradation through the effects of fragmentation and is therefore widely accepted to be the main driver of biodiversity decline (SOE, 2006).

In NSW, native vegetation clearing has been identified as the greatest single threat to biodiversity due to destruction of habitat (Coutts-Smith and Downey, 2006) listed in the *Threatened Species Conservation Act 1995*, NSW and the *Environment Protection and Biodiversity Conservation Act 1999*. The clearing has mainly taken place in grassy woodland areas for pasture improvement by the application of fertilizers, ploughing and the sowing of introduced grasses and clovers (Keith, 2004)

The constraints imposed by steeper terrain and less fertile soils wet and dry sclerophyll forests on these areas have suffered less clearing for agriculture. Semi-arid woodlands have suffered low to moderate levels of clearing (10–60%) (SOE 2006), although activity in these ecosystems has increased in recent decades. The eastern fringe of the semi-arid zone continues to be transformed by the fastest rates of clearing in NSW (DLWC, 2002), driven by an expansion in broadacre farming and the spread of irrigation. The impacts of clearing continue, or even intensify, after clearing has ceased, due to the ongoing effects of habitat fragmentation on the remaining biota (SOE, 2006). While most arid shrublands and grasslands are not subject to extensive clearing, they are affected by overgrazing (DECC, 2008).

Quantifying land use, and particularly changes in land use, remains a challenge. The state, territory and Commonwealth governments have agreed to a national methodology to assess land use, land cover and land management (BRS, 2001). While existing data sets are available from different sources, they tend to be fragmented and incompatible with each other (NLWRA, 2005), and new datasets based on the agreed national methodology are yet to be finalized. In NSW, land use mapping is carried out based on the Australian Land Use and Management Classification system (BRS, 2001). However, a commitment to provide regular updates, or a time series, is needed to allow reporting on changes in rural land use. While much information has been collected on native vegetation from a variety of perspectives, remote-sensing technologies, though promising, have demonstrated as an adequate solution at state level and much lower resolution. Reliable data on the location, extent, purpose and effectiveness of on-ground revegetation works is also badly needed. The statewide natural resource management (NRM) target relevant to this theme is 'By 2015 there is an increase in native vegetation extent and an improvement in native vegetation condition' (SOE, 2006). There is a need for further data on a landscape and state-wide basis to provide a full picture of progress towards the target.

1.4 Land use/land cover and vegetation change detection techniques

There are a variety of opinions and suggestions about the selection of the most effective and appropriate techniques for change detection studies (Lu et al., 2004). Therefore, it is difficult to decide which change detection algorithm will suit a specific problem. A review of different change detection techniques used in previous research would be of great help to select methods to aid in producing good quality change detection results.

For any change detection project, the following conditions must be satisfied (Lu et al., 2004):

(i) Accurate and precise registration between multi-temporal images; (ii) precise radiometric and atmospheric normalization between multi-temporal images; (iii) similar phenological or seasonal conditions between multi-temporal images; (iv) selection of the same spatial and spectral resolution images if possible (Lu et al., 2004).

Different data for change detection applications are available from different remote sensors such as Landsat Multi-Spectral Scanner (MSS), TM, SPOT, and AVHRR, and have been used by many researchers in different parts of the world (Lu et al., 2004).

The aim of change detection studies is to compare the spatial representation of two points in time by controlling all variance caused by differences in variables that are not of interest and to measure changes caused by differences in the variables of interest (Green et al., 1994). Since there are many change detection techniques that can be used in even one study, the selection of the most suitable method for a given research project is not easy since different approaches, with the same environmental conditions, produce different results (Coppin et al., 2004).

1.4.1 Image differencing and image ratioing - algebra

The algebraic technique of change detection analysis is based on the selection of a threshold to determine the changed areas (Lu et al., 2004). In this group of change detection techniques, many researchers have applied image differencing and image ratioing with different combinations of spectral bands as their first choice for identifying changes, and derived satisfactory results. Conclusions and recommendations vary about whether image differencing and regression, vegetation index differencing or image ratioing is the best change detection technique. Since each method has been applied to different areas, with different data sets and under different environmental conditions, the decision on the selection of suitable method is not an easy task (Coppin et al., 2004).

1.4.2 Transformation

Various linear data transformation techniques such as Principal Component Analysis (PCA), Tasselled Cap (TC), Gramm–Schmidt (GS), and chi-square transformations have been applied to multi-temporal remote sensing data to identify changes in various land use/land cover classes. In PCA, only two bands of the multi-date image are used as input instead of all bands (Richards, 1986; Mas, 1999), and hence reducing the data volume and redundancy between bands. After transformation using two bands, the derived components contain information about change and no change areas as the first and second components, respectively, based on information common or unique in the two input bands (Chavez and Kwarteng, 1989). PCA is based on three steps: calculation of a variance–covariance matrix, computation of eigenvectors and linear transformation of data sets (Richards, 1986). Two types of PCA, standardized PCA (uses correlation matrix) and non-standardized PCA (uses covariance matrix), have been used for change detection (Singh and Harrison, 1985). PCA has certain disadvantages in not providing detailed change matrices and difficulty in interpretation, identification and labelling of changed areas.

TC transformation is carried out by assigning tasselled cap coefficients to spectral bands of two dates, a positive coefficient to the first date and a negative coefficient to the second date, as explained by Crist and Cicone (1984). This is followed by Gramm-Schmidt transformation to make the derived vectors orthogonal to each other. The three transformed images thus obtained contain information about differences in greenness, brightness and wetness, with highest classification accuracy in the greenness change image.

PCA and TC have been are the most used approaches for detecting change/no-change information, while two other GS and chi-square, are not commonly used for change detection analysis due to their complexity compared to PCA and TC transformation (Lu et al., 2004). An additional advantage of TC transformation is that the TC coefficients are scene independent compared to PCA coefficients, which are scene-dependent.

1.4.3 Classification

The classification group of change detection techniques include supervised and unsupervised classification followed by post-classification comparison of results of change /no-change identification. The aim of these methods is to produce high quality, accurate classification results from remote sensing data through the use adequate numbers of accurate training sample data, to produce accurate change results after comparison. However, selection of sufficient numbers of high quality training samples to truly represent each land use/land cover class is laborious and time consuming and requires thorough knowledge of the study area in order to obtain high quality classification results. The situation is more difficult in the classification of historical data when there is no or insufficient ground or area information, making accurate classification a challenge and often leading to unsatisfactory change detection results (Lu et al., 2004). The change detection results are often represented in the form of matrix showing land use/land cover dynamics of pixels changes from one class to other, providing a detailed description of changes over a specified period of time and minimizing the effect of atmospheric and environment difference between the multi-date images. A detailed review of quality assessment of different image classification algorithms for land cover mapping and accuracy assessment has been summarized by Smits and Dellepiane (1999). These techniques have been used by many researches in different types of land cover change detection analysis with good results (e.g. Xiuwan, 2002; Petit and Lambin, 2002; Li and Zhou, 2009; Wang et al., 2009).

1.4.4 Land use/land cover change using spatial pattern metrics

Numerous landscape metrics have been developed to characterize the patterns and configurations of different land cover types in a landscape. Categorical maps generated from remote sensing data can then be used for landscape characterization to better understand spatial arrangements between different cover classes, particularly forest fragments (Read and Lam, 2002). These spatial arrangements are expressed numerically in the form of landscape indices or pattern metrics and have been used in many studies to assess land cover change and its impact, ecosystem health, or as variables for models that support environmental assessment and planning efforts (e.g.Botequilha Leitão and Ahern, 2002; Fuller, 2001; Gergel, 2005; Griffith et al., 2000; Liu and Cameron, 2001).

Although many pattern metrics have been used for various applications, there exists neither a single definition of nor a standardized process for the selection of pattern metrics (Civco et al., 2002), and their sensitivity to remote sensing data characteristics have not been thoroughly evaluated (Frohn, 1998). The complex behaviour of pattern metrics in terms of scale, resolution, measurement techniques and their inter-correlations still requires research (De Clercq et al., 2006). For instance, it is often uncertain whether the changes in metric values are due to actual change in landscape patterns or due to temporal variations in remote sensing data characteristics. Effective pattern metrics should only be sensitive to real spatial patterns and not to random sampling variations (De Clercq et al., 2006).

More than 100 pattern metrics can be computed using freeware such as FRAGSTAT (McGarigal and Marks, 1995), Patch Metrics (Rempel et al., 1999) and others (Crews-Meyer, 2002; Cumming and Vervier, 2002; Stanfield et al., 2002). However, many pattern metrics are highly correlated (Cain et al., 1997; Riitters et al., 1995). Efforts have been made to identify a minimum set of pattern metrics that describe landscape pattern adequately. Multivariate data analysis using principal component analysis (PCA) and factor analysis (FA) are the most commonly used methods to reduce pattern metrics data (Griffith et al., 2000; Honnay et al., 2003; McAlpine and Eyre, 2002; Stanfield et al., 2002). These methods identify a small number of components, which are then interpreted in terms of their dominant characteristics and underlying causes (Griffith et al., 2000). Multivariate data analysis requires large data-sets and several landscape units to be statistically consistent (e.g.Cumming and Vervier, 2002; Schmitz et al., 2003). A few empirical landscape studies apply pattern analysis to only one landscape e.g. (Griffith et al., 2000) and are useful because they tackle problems at relevant scales, but the validity of making statistical inferences with such an approach is seriously compromised (Li and Wu, 2004). Gustafson (1998) overcame this by generating artificial landscapes (called neutral models), but the technique was difficult to relate to pattern metrics in real landscapes (Li and Wu, 2004). Therefore, the behaviour of pattern metrics in real landscapes over time needs further investigation (Griffith et al., 2003). Irrespective of the landscape unit used, pattern metrics require rigorous validation in order to be interpreted and applied with confidence (McAlpine and Eyre, 2002).

1.5 Applications of time series data in land use/land cover change and predictive modelling

Most of the previous change detection studies, as discussed above, have used bi-temporal images for change identification and modelling (e.g. Mertens and Lambin 2000; Kennedy et al., 2007; Mena, 2008; Huang et al., 2010), despite the potential of long-term data series, particularly from Landsat. These studies have satisfactorily identified the spatial pattern and rate of overall change for a given period of time. However, it would also be useful to understand the transition processes responsible for land cover change, when change occurs and the possible impact of changes on natural resources over a given period (Mertens and Lambin, 2000; Petit et al., 2001; An and Brown, 2008; Mena, 2008). At the same time, long-term transition processes often follow non-linear and reversible pathways (Mertens and Lambin, 2000; Braimoh and Vlek, 2005) and thus land cover change predication from bi-temporal data appears improbable. For example, Mertens and Lambin (2000) modelled land cover change trajectories over several observation years and reported an improvement in the projection of areas with a high probability of change compared to the projections based on observations from only the previous period alone. In a similar study, through analysis of time-series data of five dates, Vågen (2006) found a nonlinear temporal pattern of deforestation in Madagascar and concluded that such a pattern could only have been observed due to the use of time-series data. Temporal sequences of land cover classifications derived from satellite images on more than two dates are needed for better characterization of land cover dynamics and also for change predictions. Recently, free Web-based access to the Landsat archive for the public has greatly improved the accessibility of multi-temporal Landsat data (USGS, 2008), thus providing an opportunity to advance detailed land cover change analysis using a series of multi-temporal data from recent decades.

1.5.1 Markov transition probability modelling

Temporal series data not only provides an opportunity to project the probability of temporal change developments in land cover but also interpolates land cover distributions between the observation dates (Lambin, 1997). Modelling the change process using a Markov chain model (MCM) can be used to interpolate the temporal data and for short-term change projections. One of the basic assumptions of the MCM is to regard land use and land cover change as a stochastic process, and different categories as the states of a chain (Weng, 2002). A chain is defined as a stochastic process having the property that the value of the process, X_t, at time t, depends only on its value, X_{t-1}, at time $t-1$, and not on the sequence of values X_{t-2}, X_{t-3},….X_0 that the process passed through in arriving at X_{t-1} (Weng, 2002).

However, there are three issues where the observed changes violate some of the assumptions of a first-order Markov model (Petit et al., 2001). The issues are: non-stationarity, spatial dependencies and information on historical land cover change. As land use and land cover change reflects the dynamics and relationship of economic, social, and biophysical factors over time, it would be improbable to expect stationarity in land cover data. That means the rates or probabilities of transitions among cover types vary through time and are not similar across all change periods. Therefore, the projection from one time period need not match the state of the change in the next time period. This is because the Markov model is a complete empirical description of the observed changes in the proportion of cover types and, as a result it must reproduce the aggregate changes for the period for which the model was constructed (Petit et al., 2001). However, Weng (2002) suggested that it might be practical to regard land cover change to be reasonably stationary if the time span is not too great.

The second issue of spatial dependencies implies that the changes depend on neighbourhood effects that influence the probability of changes among cover types. Soil type, topographic position, distance from anthropogenic activities or other environmental variables are a few common factors that influence land cover change. These factors drive the modelling approach away from a simple Markov framework, towards models where the transition probabilities depend not only on the current state of the system, but also on some other stated conditions (Eastman, 2000; Jiang et al., 2008; Wu et al., 2009; Araya and Cabral, 2010).

The third and final issue related to MCM is about the information on historical land cover change. Prior land use information leaves a legacy in landscape dynamics, implying that the dynamics are not first-order. This leads to higher-order Markov models (e.g. in a second-order model, one must know the state of the system at time *t–1* and *t–2* to predict its state at time *t*) (Baker 1989, and see, e.g., Acevedo et al. 1995, 1996). The issue of spatial dependencies on land cover change in Markov chains can be resolved by the use of a Cellular Automata Markov Model (*CA-MCM*) (Lo and Yang, 2002; Myint et al., 2010; Ahmad and Ahmad, 2012), which simulates spatial dynamics in raster lattices by conditioning the fate of a focal cell on its state and the states of its neighbour cells.

1.6 Use of land cover change in habitat configuration assessment

Loss and degradation of terrestrial habitat is a major environmental concern worldwide and a variety of ecological indicators have been developed to document the current status and trends in natural resources in terms of land use trends (Tiner, 2004). The size, shape and spatial relationships of land cover types influence the dynamics of populations, communities and ecosystems (Drielsma, 2007). The ability to describe and quantify landscape structure and connectivity is necessary to successfully characterize ecological processes and prioritize habitat networks for conservation management. Time series land cover change analysis, therefore, can be used to assess the impact of change on terrestrial habitat configuration in terms of change in effective habitat area and habitat connectivity. Though progress has been made in the modelling of spatial pattern (e.g. Guisan and Zimmermann, 2000; Drielsma et al., 2007), there is a need for understanding the relationship between species survival in relation to landscape pattern and processes. In practice the pattern and processes need to be better integrated (Turner, 1989; Li and Wu, 2004; Ferrier and Drielsma, 2010). According to With et al. (1997), the functional relationship (i.e. process) among habitat patches (pattern) is called landscape connectivity. The importance of spatial processes in species survival has brought attention to incorporate these processes through various habitat modelling approaches (e.g. Tischendorf and Fahrig, 2000b; Fischer and Lindenmayer, 2006). The conceptual frameworks of models vary greatly in terms of spatial, temporal, structural, process, behavioural and geometric complexities (Loehle, 2004). There might be a possibility of getting more realistic and reliable results from complex models, the process, however, is always associated with additional effort and expenses. Therefore, there is a need for ecologically precise, simple and easily executable modelling techniques for routine conservation assessment and land use planning.

A very few materials available that deals with identification of suitable season for land cover and vegetation mapping explaining how seasonal variations affects the classification accuracies within a single year and also over other years of varying rainfall conditions. Understanding of seasonal land cover spectral characteristics is desirable as it helps in selection of images of a particular season based on maximum contrast between land cover categories, thus enabling in selection of images in the same season in other years for change identification. The images of most suitable period in a given year and selection of same month over different observation years warrant minimum confusion between land cover class and aid in accurate change detection process particularly when post classification change detection method is used and land cover categories in a given region is susceptible to varying amount of rainfall and temperature. However, no such study was found in the past dealing this aspect of change detection process. Further, very few studies focussed on estimating yearly land use process in any region when one season data is used to refine classification in other season and logically aggregated to produce annual land cover classification showing seasonal change. The current study addresses these important issues and providing some insight on the topic.

The another important issue identified through literature was the selection of most appropriate land cover change detection techniques as decision on selection process is often influenced by the study region landscape complexity and type of data used for analysis. For different climatic areas, the method that suits best for seasonal land cover change identification remains uncertain and hence remains topic of research. When binary images from one or more spectral bands is used for land cover change/no-change identification, determination of appropriate threshold levels for change/no-change identification is another critical factor that influences change detection result accuracy. Most of the methods used in the past determined the threshold values based on the standard deviation (SD) from the mean, assuming the amount of change (due to increase or decrease in brightness values) to be symmetrically distributed on a standard normal curve, which is not always true. However, considering the asymmetrical nature of distribution histogram for the two sides, there is a need to identify better method for optimal threshold value determination and comparing the performances of new method to those from the traditional techniques.

A large volume of work has been done in the past on identification of land cover change from landscape pattern metrics. However, because of high correlation among the metrics, researchers observed that determining the best set of landscape metrics for spatial land cover pattern monitoring is challenging and there is no standardized test that can be used to assess the quality of a particular metric. Further, metrics are not found thoroughly evaluated with respect to remote sensing data characteristics, such as their behaviour towards variation in spatial and temporal resolutions, number of land cover classes or dominant land cover categories. There is a need of more research on this topic to overcome the difficulty in ascertaining whether a change in a metric is due to landscape pattern change or due to the inherent variability in multitemporal data.

Though a vast amount of work has been done on modelling land cover change using time-series Markov-based transition, however, a very few studies addressed the two major issues of stationarity and the neighbourhood effect associated with Markov models. The issues are important for the evolution of future scenarios using a Markovian model through incorporation of other spatial variables, which drive changes, in more sophisticated models, lead to improved forecast as compared to simple model. This provides scopes for researchers to delineate scenarios according to specific conditions. There is also a need for modelling terrestrial habitat configuration and identifying the changes in effective habitat area due to land cover change. Though progress has been made in the modelling of spatial pattern, the process has required additional effort and expenses, and therefore, there is a need for ecologically precise, simple and easily executable modelling techniques for routine conservation assessment and land use planning.

1.7 General aims

The main objective of this study was to investigate the potential of remote sensing, GIS and modelling techniques for seasonal and decadal land cover change analysis, and assessment of long-term pattern of land cover change for future change predictions and impact of land cover change on terrestrial habitat configuration. This major objective has been broken down into the following specific aims:

a) Identifying which season satellite data is suitable for land cover and vegetation mapping in the study region and how seasonal variations affect classification accuracies within a single year and also over other years of varying rainfall conditions

b) Investigating how consideration of seasonal variability in land cover classification improves classification accuracies, land cover seasonal change detection using three-date satellite data composites for better understanding the extent of change from one season to another, and estimating overall landcover in a given year through a process of referential refinement and aggregation

c) Investigating how binary images assist in seasonal land cover change identification through comparison of 11 different change images using various techniques and proposing a new method called the "Independent two-step thresholding technique" for identifying and quantifying changes that occurred because of increases and decreases in pixel brightness values

d) Testing the proposed method of thresholding by comparing the results to those from the traditional techniques by using the entire reference data set for optimal threshold level determination and accuracy evaluations

e) Identifying long term land cover change (1972–2009) using four change period datasets (1972–87; 1987–1993; 1993–99 and 1999–09), comparing the performances of traditional pixel-based classification to those from object-based segmentation and classification approaches and reporting the change processes in details.

f) Determining the best set of landscape metrics for spatial land cover pattern monitoring by proposing a ranking-based procedure through the computation of difference-based indices called Max–Min/Max normalization of metric datasets

g) Analysing patterns of land cover change (1972–2009) using time-series Markov-based transition modelling by addressing two major issues, stationarity and the neighbourhood effect associated with Markov models, and predicting land cover change for the year 2019

h) Modelling terrestrial habitat configuration and identifying the changes in effective habitat area due to land cover change from 1972 to 2009.

1.8 Description of study area

The research area selected for this study forms part of three NSW bioregions, namely the New England Tableland, Nandewar and Brigalow Belt South Bioregions, on the basis of their dominant landscape-scale attributes. Bioregions have been further divided into sub regions based on finer differences in biophysical attributes including geology and vegetation (Morgan and Terrey, 1992). Because sub regions provide more detailed information about the landscape, they can be used for finer scale planning. The climate is subhumid and temperate in the eastern tablelands portion of the region with a mean annual rainfall of 800–1000 mm, and a temperature ranging from 0 –26 ° (January maximum of 23–26°C and a July minimum of 0–2°C (BoM, 2010). On the plains in the west of the region, mean annual rainfall is 550–650 mm, and a temperature ranging from 5–33° (with a January maximum of 33°C and a July minimum of 5°C). The wide variety of duplex and gradational soils mainly support open evergreen sclerophyll forests and woodlands dominated by eucalypts where the vegetation has not been cleared or thinned for cropping and grazing. Rainfall decreases from east to west across the region. The dual summer–winter rainfall and temperature variations from warm summers to frosty winters support herbaceous vegetation dominated by both summer-active and winter-active or yearlong green plants (native and introduced) (Ledge and Whalley, 1989). Figure 1.1 shows the location of study area.

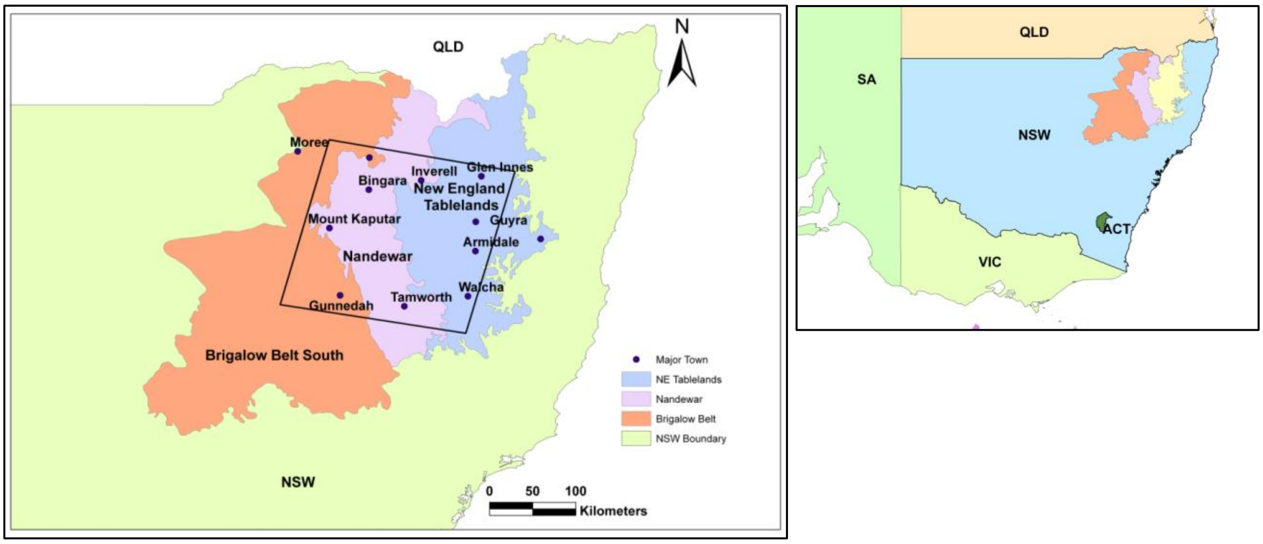

Figure 1.1 Location of study area.

One of the major land cover categories in the region is grazed pasture dominated by summer and winter-active plants or a mix of both. ‘Improved’ (sown, fertilized) pastures on the tablelands and slopes are generally dominated by, winter-active and yearlong green (C3) grasses and clovers or lucerne. Pastures on the plains, on the other hand, are increasingly sown to tropical summer-active (C4) grasses.

Natural resource degradation in rural regions of Australia is one of the many environmental problems, when many natural resource systems, particularly in agricultural landscapes, are in decline (Australian State of the Environment Committee 2001). Faltering ecological function across landscapes is a critical issue because of its direct impacts on biodiversity and the processes it sustains and also the social consequences arising in the dependent communities. The cultural landscapes of the NSW reflect the modifications made to the natural landscape by human activities, and demonstrate the interactions between people and places. They also illustrate the ability of the human species to change environments to suit their needs and desires, unlike other species. Communities of NSW are faced with a number of environmental challenges affecting their well being. These include soil loss, landscape degradation and species loss.

1.9 Format of thesis

The thesis is presented as a series of journal articles, two of which have been published or accepted for publication, with six presently under review. The theme linking these studies is the understanding of seasonal land cover spectral characteristics that influence (i) the time period suitable for data selection for studying long-term land cover change, (ii) analysis of rate and pattern of change, and future change and its possible impact on wildlife habitat over time.

This thesis comprises ten chapters including this Introduction, the experimental chapters and Conclusions. The Introduction sets out the aims of the study and reviews briefly the literature relevant to the area of study. Each experimental chapter (2–8) is presented in the format of journal articles, as submitted, with an abstract, introduction, aims, methods, results, discussion and conclusion.

Chapter 2 determined the effect of seasonal spectral variability on land cover classification of Landsat TM by comparing accuracies in different seasons in a mid-latitudinal (29°30'–31°0'S) region with summer and winter rainfall, a broad altitudinal range, a temperate to subtropical climate and diverse land uses (e.g. summer and winter crops, nature conservation). This work has been published in the journal of *Photogrammetric Engineering and Remote Sensing*.

Chapter 3 investigated seasonal land cover change from a three-date satellite data composite using a range of techniques and estimated the overall land cover of the region through a process called referential refinement and aggregation. The work is has been published in *Journal of Applied Remote Sensing*.

Chapter 4 proposed a method for bi-temporal seasonal land cover change /no-change identification by testing it on 11 change images and determining separate threshold values for change due to increased and decreased brightness values compared to no-change areas. This work has been published in the *International Journal of Remote Sensing*.

Chapter 5 is a continuation of Chapter 4, and compared the proposed method for determining bi-directional threshold values (for both increased and decreased in brightness values) with the traditional thresholding methods and highlighted the advantages of the proposed method for thresholding compared with conventional thresholding. The paper is under review with the *ISPRS Journal of Photogrammetry and Remote Sensing*.

Chapter 6 investigated long-term land cover change in the region through the analysis of five datasets from 1972 to 2009 by comparing results from traditional pixel-based classifications and a new object-based segmentation and classification method.

Chapter 7 proposed a new rank-based method for the selection of land cover pattern metrics by determining the metrics' sensitivities towards spatial data characteristics such as spatial and temporal resolutions, dominance, land cover class, and number of land cover classes and testing their effectiveness in identifying changes using time series land cover data from 1972–2009. This work is under review with *Photogrammetric Engineering and Remote Sensing*.

The final two experimental chapters are mostly related to land cover change modelling and assessment of impact of land cover change on terrestrial wildlife habitat configuration. Chapter 8 applied Markov Transition modelling approach to land cover change processes for different transition periods and also predicts change to the year 2019 by addressing two major issues associated with Markov chain modelling: stationarity and the neighbourhood effect. The work is under review with *Photogrammetric Engineering and Remote Sensing*. Chapter 9 described the impact of land cover change on habitat configuration by automated mapping of habitat linkages in the landscape using the concept of metapopulations and the least cost path algorithm from graph theory. The work is under review with *Ecological Informatics.*

Chapter 10 presents the general conclusions of the thesis and describes the research main findings of each chapter. Research implications are described and future research needs are highlighted.

CHAPTER 2

Seasonal Variation in Land Cover Classification Accuracy in a Diverse Region

This chapter has been published as:

Sinha, P., Kumar, L., & Reid, N. (2012). Seasonal Variation in Land–cover Classification Accuracy in a Diverse Region. *Photogrammetric Engineering and Remote Sensing, 78*(3), 271–280.

CHAPTER 3

Three-date Landsat TM composite in seasonal land cover change identification in a mid-latitudinal region of diverse climate and land use

This chapter is published in *Journal of Applied Remote Sensing*

Sinha, P., Kumar, L., & Reid, N. Three-date Landsat TM composite in seasonal land-cover change identification in a mid-latitudinal region of diverse climate and land use *Journal. Applied Remote Sensing* 6(1), 063595 (Oct 30, 2012).
doi:10.1117/1.JRS.6.063595.

CHAPTER 4

Binary Images in Seasonal Land Cover Change Identification: A Comparative Study in Parts of New South Wales, Australia

This chapter published in *International Journal of Remote Sensing*

Sinha, P. & Kumar, L. Binary images in seasonal land-cover change identification: a comparative study in parts of New South Wales, Australia
International Journal of Remote Sensing, 34:6, 2162-2186**.**
http://dx.doi.org/10.1080/01431161.2012.742214

CHAPTER 5

Independent Two-step Thresholding of Binary Images in Inter-Annual Land Cover Change/No-Change Identification

This chapter is accepted for publication in *ISPRS Journal of Photogrammetry and Remote Sensing*

Sinha, P., and Kumar, L. Independent Two-step Thresholding of Binary Images in Inter-Annual Land Cover Change/No-Change Identification *(in press)*

CHAPTER 6

Comparison of pixel and object based land cover changes over a 37-year period in parts of Brigalow Belt South Bioregions (BBSB) of NSW, Australia

This chapter is to be submitted for publication

Sinha, P., Kumar, L. Comparison of pixel and object based landcover changes over a 37-year period in parts of Brigalow Belt South Bioregions (BBSB) of NSW, Australia.

CHAPTER 7

Rank-based method for selection of landscape metrics for land cover pattern change detection

This chapter is under review with *Photogrammetric Engineering and Remote Sensing*

Sinha, P., Kumar, L., and Reid, N. Rank-based method for selection of landscape metrics for land cover pattern change detection *(Submitted)*

CHAPTER 8

Markov land cover change modelling using multiple pairs of time-series satellite images

This chapter is under review with *Photogrammetric Engineering and Remote Sensing*

Sinha, P., and Kumar, L. Markov land cover change modelling using multiple pairs of time-series satellite images *(Revision Submitted)*

CHAPTER 9

Time-series Effective Habitat Area (EHA) Modelling using Cost-benefit raster based technique

This chapter is under review with *Ecological Informatics*

Sinha, P., Kumar, L., Drielsma, M., and Barrett, T., Time-series Effective Habitat Area (EHA) Modelling using Cost-benefit raster based technique

Chapter 10 Conclusions

10. 1 Introduction

This thesis has provided a better understanding of the land cover change process and the current situation in northern NSW, Australia. Various reports on land cover change indicated that, after 1997, there was significant change across NSW in the agricultural sector (DECC, 2006), as well as transfer of state forests to the conservation estate, and continuing urban growth in Sydney's west and along the coast. With regards the natural environment, according to DECC (2006), nearly 50% of native forests in NSW have been cleared and more than 50% of semi-arid lands have been degraded since European settlement. There are hundreds of plant and animal species that are considered endangered, creating a major biodiversity crisis (www.nccnsw.org.au). Biodiversity loss was reportedly serious environmental problem in the Commonwealth State of the Environment Report (1996), which acknowledged the lack of data and scientific understanding about the issue. The threatening processes identified in that report persist today (www.nccnsw.org.au).

The overall aim of the research was to investigate the potential of remote sensing, GIS and modelling techniques to study seasonal and long-term (nearly four decades) land cover change and assess long-term patterns in land cover change for future change predictions. The research also assessed the impact of land cover change on terrestrial habitat configurations. The research has significance in understanding the land cover change processes in the region, as abrupt change has a lot of environmental and ecological consequences in terms of alteration of entire landscapes (Houghton, 1994; Lambin, 1997), impacting or changing the biodiversity (Xiuwan, 2002; Falcucci et al. 2007), nutrient and hydrological cycles (Hobbs,1993) as well as global environment (Turner et al., 1994; Reid et al., 2000; Xiuwan, 2002) and climate (DeFries et al., 1997; Luvall, 1997; de Sherbinin, 2002).

This concluding chapter summarizes the main findings of the research under two headings: (1) applications of remote sensing in seasonal and long-term change analysis, and (2) landscape characterization and modeling of land cover change and habitat configuration. It goes on to highlight the methodological development attained through this research, and discusses future research needs.

10.2 Summary of main findings

10.2.1 Remote sensing based seasonal and long term land cover change

For remote sensing to be most effective, it is important to develop techniques that distinguish effectively between land cover classes based on their spectral characteristics in different seasons and for better understanding of seasonal land cover changes transitions taking place in land cover classes between seasons. The first five studies in this thesis focused on this aspect of remote sensing applications.

Seasonal variations in land cover classifications are important since accuracies can vary seasonally within and between years and the selection of a particular season can have a large impact on the accuracy and reliability of the resulting classification. The study investigated the issue of the selection of the most appropriate season for land cover mapping by studying the spectral response of land cover categories in different seasons in a mid-latitudinal (29°30’–31°0’S) region with both summer and winter rainfall, a broad altitudinal range, a climate varying from temperate to subtropical and diverse land uses (e.g. summer and winter crops, and nature conservation). Among the different band combinations used in classification, including original TM bands and derived tasselled cap (TC) principal component analysis (PCA) and NDVI images, the raw band B1–4 classification was the best across all dates. The highest accuracy was obtained with a mid-summer (January) image (96.5%, Kappa 0.96) and the lowest with an early spring (September) image (86.7%, Kappa 0.84). The superiority of mid-summer images in generating highly accurate land cover classifications was demonstrated by the analysis of additional images under varying rainfall conditions in different years. The approach used in this study of selecting images in the season giving the highest accuracy in land cover classification, enabled the selection of images in the same season in other years for long-term change identification. The method used in this study can be extended to other regions where the spectral response of land cover categories varies markedly with seasonal conditions.

Investigation of class-wise land cover classification accuracies in different seasons provided scope to select the most suitable season or month for mapping individual classes. This was done using conditional Kappa ( ) coefficients which confirmed that most classes showed 100% agreement with the January classification. Among the different methods used for investigating of seasonal dynamism using three-date data composites, the RGB–NDVI was most effective followed by the NDVI–TC2, supervised (supB1–4), and density slicing (DS–NDVI and DS–TC2) methods. The aggregate output clearly provided a means for understanding overall land use distribution in the region. The major activities identified were livestock production from grazed pastures, both natural and sown, and crop and pasture production as a part of crop–pasture rotation systems.

Considering the need for information on overall change/no-change in land cover over short intervals and understanding the usefulness of binary change images for such assessment, the requirements for highlighting areas where land cover brightness values increased or decreased (mostly due to change in vegetation density), or remained unchanged were identified. Also, the issues related to traditional means of threshold determination for change/no-change identification were investigated. The study tested and compared 11 different binary change detection methods with respect to their capability in detecting land cover change/no-change information in different seasons. The study proposed a new method for determining optimal threshold values by considering the left and right tails of a histogram of change image separately and computing two separate means and standard deviations (SD) for spectrally decreased, (i.e. left tail as $Mean_L$, SD_L) and spectrally increased, (i.e right tail as $Mean_R$, SD_R). For the left tail (negative change), the threshold value was determined as pixel value < $Mean_L+C*SD_L$, and for the right tail (positive change), pixel value > $Mean_R–C*SD_R$ (where C=critical value). No-change pixels lay in-between these two thresholds. Different C-values were tested and an optimal C and threshold value was determined based on highest Kappa or overall accuracy (e.g. Fung and LeDrew, 1988; Hayes and Sader, 2001; Pu et al., 2008). The results indicated that, irrespective of the method used, the accuracy assessment and change/no-change validation from NDVI-based techniques outperformed other techniques in the change detection process (overall accuracy > 90% and Kappa value > 0.85 for all six change periods). Due to the simplistic nature and relative ease in identifying both negative and positive changes from difference images, the NDVI differencing technique was recommended for seasonal land cover change identification in the study region.

The effectiveness of the proposed method to determine the change/no-change threshold described above was evaluated. The issue of the asymmetrical nature of the histogram of change image was tested by comparing the results from my proposed 'Independent Two-Step' threshold approach with those from the conventional (mean ± C*SD) method and the dependent two-step threshold method of Mas (1999), where a major issue was the use of reduced subset of sample points to determine threshold level and thus the reliability of Kappa. These two issues were efficiently dealt with using the proposed thresholding techniques and by using the entire reference data set for optimal threshold level determination. The relative performances of the three methods in the distribution asymmetry test was an improvement of ~3% in overall accuracy and of ~0.04 in Kappa with the independent two-step method.

Investigations of the relative performance of object-based and pixel-based analysis in land cover classification and in change identification from Landsat MSS and TM data over a 37-year period for five successive change periods, 1972–73, 1987–88, 1993–94, 1999–00 and 2009–10, were carried out. Object-based classification was ~2–6% more accurate than the maximum likelihood classification (MLC) and significantly so ($P < 0.001$). The results from the object-based classification were more realistic with fewer illogical errors than the MLC. A gradual conversion of natural vegetation (mainly native pastures and some woodland) to various more intensive agricultural activities and mining took place over the entire change period. This study demonstrated a way to carry out change detection analysis in the absence of reference data for earlier dates through a process called signature extension. It also provided scope to compare the results of a parametric classifier (MLC) with non-parametric ones (*k*-NN).

10.2.2 Landscape characterization, modeling land cover change and habitat configuration

Many landscape metrics have been proposed to quantify landscape pattern and analyse change. This study evaluated 33 landscape metrics with respect to remote sensing parameters, such as their behaviour towards variation in spatial and temporal resolution, the number of land cover classes and to dominant land cover categories. One difficulty associated with applying landscape metrics to land cover change analysis is the selection of the most appropriate and effective metrics, to measure landscape changes. This study proposed a new rank-based metric selection process through the computation of four difference-based indices (β, γ, ξ and θ) using a (Max–Min/Max) normalization approach. The landscape metrics selected on the basis of the proposed methods were successful and effective in identifying changes over five different change periods (1972–73, 1987–88, 1993–94, 1999–00 and 2009–10) in two contrasting provinces, Liverpool Plains and Liverpool Range, of Brigalow Belt South bioregion of NSW. This method was simple and straightforward, and has the potential to discriminate among hundreds of metrics when selection of an appropriate set of metrics for a particular study can become difficult.

Modelling the change process using time series satellite data using a Markov chain model (MCM) provided an opportunity for detailed land cover change pattern investigation and also helped in projecting the probability of temporal change developments into future land cover change. The study addressed two major issues associated with the use of Markov models in land cover change predictions: the issues of stationarity of change and the impact of neighbouring cells on change areas. Computation of three short-term transition matrices to predict land cover distribution in the near future was carried out to address the issue of stationarity by comparing predicted and observed results. Very good agreements between the two indicated consistencies in land cover change and the usefulness of the model to predict near future landscape pattern. The neighbourhood effect issue was addressed by the incorporation of spatial components in a Cellular Automata (CA)-based MCM, and, showed marginal improvements over MCM. The added advantage of CA-MCM to incorporate spatial variants was suitable for predicting land cover change to the year

2019. The land cover prediction for 2019 indicated that future land cover changes would continue to affect natural vegetation, which would continue to decrease through conversion to agriculture or more intensive agricultural land uses.

Analysis of the impact of land cover change on habitat configuration by automated mapping of landscape-scale habitat connectivity using the metapopulation concept and the least cost path algorithm indicated that there was a loss of terrestrial habitat in the Liverpool region over the entire change period. Greater loss occurred on the loss slopes on the southern side of region through and development of improved pasture and crop production, whereas forests on the northern slopes of the region were mostly still present.

10.3 Main conclusions

Several conclusions can be drawn regarding the land cover characteristics in the study region:

(a) Irrespective of varying rainfall conditions, summer (December to February) was the best season for land cover mapping in the region.

(b) Seasonal dynamism indicated two seasonal transitions when major changes in vegetation cover are observed: the first transition is from winter to early summer and the second transition is from early spring to autumn.

(c) Long-term change analysis carried out in two provinces of the Brigalow Belt bioregion (1972–2009) indicated that native vegetation cover, natural pasture (NP) and evergreen forest and woodland (EFWL), declined in the regions over the study period, with a marked decline after 1993. At the same time the area of agriculture-related activities increased. Similar findings were reported by Pressey et al. (2000) and the EPA (2000): clearing for cropping and grazing was greater between 1995 and 2000 after the introduction of the *Native Vegetation Conservation (NVC) Act*, 1997, NSW (BCASR, 2002).

(d) The land cover prediction for 2019 indicated that future land cover changes would continue to affect native vegetation, which would continue to decrease over time through conversion to more intensively used agricultural land.

(e) Habitat configuration analysis and mapping of landscape-scale habitat connectivity in the Liverpool range indicated a loss of terrestrial habitat in the region over the change period, not only contributing to native biodiversity loss but exacerbating the threat to remaining native biodiversity.

10.4 Implications of the Study

This study has demonstrated the potential of various image processing techniques for improved land cover mapping and change identification and also modeling land cover change for future change. The superiority of mid-summer images in generating highly accurate land cover classifications under varying rainfall conditions is a useful finding for managers in the region to identify the most suitable season for land cover mapping, thus enabling the selection of images for long-term change identification. Despite seasonal dynamism, the aggregated output clearly provides the means for understanding overall land use distribution in the region, the major activities identified in the region being livestock production on grazed pastures, both natural and sown, and crop and pasture production as a part of crop–pasture rotations.

The methodology developed for determining the optimal threshold value for change/no-change identification by considering both the increase and decrease in brightness values over time provides scope for users to not only address the issue of asymmetry in the distribution of change histogram but also to identify change in both directions. The results obtained from a proposed new method were tested with conventional techniques, and the improvements in results obtained through the proposed method should motivate users to apply it in their studies.

The rank-based metric selection process through computation of four difference-based indices (β, γ, ξ and θ) developed in this study provides a solution to the difficulties associated with selecting the most appropriate effective metrics from a large number capable of highlighting changes. The method, being simple, straightforward and capable of dealing with hundreds of metrics, will be useful for analyst in this field.

10.5 Synthesis of study

The study applied a variety of image processing and change detection processes on remote sensing data of different spectral and spatial resolutions, and successfully mapped land cover in different seasons and years and identified changes between two observation periods. The different approaches used for land cover mapping and change process identification can be used in a variety of applications under any conditions with any type of data. The use of original spectral bands, along with the derived ones, can contribute towards different possible ways for feature extraction from remote sensing data. The seasonal land cover variations mapping can be useful in understanding of cropping pattern in any region, through continuous monitoring of seasonal vegetation phenology. The use of binary images in change detection process and proposed thresholding technique can provide a means for dealing with asymmetry of change distribution histograms and also can be applied in a variety of applications such as forest fire monitoring, or any other applications when rapid assessment of change is needed. The long term change detection technique provides a means for using time series remote sensing data for identification of pattern of change and also the comparison of object and pixel-based techniques in change detection can be seen as an alternative to traditional post classification comparison techniques. The method for selection of suitable landscape pattern metrics for change identification, and sensitivity analysis of selected metrics with respect to spatial data characteristics can contribute to other applications where choice on selection of few metrics are needed for change identification. The Markov change modelling used in this study provided a scope of addressing the issue of stationarity of Markov chains and also impact of neighbourhood conditions in land cover change prediction. The two issues addressed here can be used in other applications such as urban land cover change modelling and future change prediction. The main driving force of land cover changes in this region was identified as vegetation clearing. Extensive logging has reduced the original tree size classes in forests on basalt soils on the Liverpool Range, while biologically significant dry rainforests were vulnerable to fire, grazing from feral animals, including goats and rabbits, and invasion by exotic plant species. The succession of droughts over the three decades was an additional factor of change in the natural vegetation areas in combination with land use extensification. The remote sensing analysis reveals, however, that land cover changes have increased in recent years compared to the seventies and eighties when the annual rate of land cover change was more than 10%.

Finally, the modelling of habitat connectivity and effective habitat change monitoring using time series, using raster based cost-benefit approach demonstrates a means for understanding of biodiversity change in any region over time and also the pattern of change can be used for future biodiversity condition predictions. Overall, the study demonstrated applications of a number of image processing and modelling techniques using time-series remote sensing datasets in different land use based applications in northern NSW. The outcome of long-term change analysis and modelling future change provides scope for land managers and policy makers in the region to better understand the amount and pattern of change that has occurred since 1972 and future trends. These results should inform policy formulation for sustainable land management in the study region.

10.6 Limitations and recommendations

The investigation of suitable periods for land cover mapping and seasonal land cover dynamics was carried out for parts of just three bioregions (New England Tablelands, Nandewar and Brigalow Belt South), mainly because of time and data volume constraints. However, the spatial constraints has not affected the depth and quality of the research, as the aim was to understand seasonal variations in land cover spectral characteristics and identify suitable periods when the classification accuracy was maximal. Similarly, land cover change identification in different seasons was restricted to the study region area only, as the aim was to understand the general change pattern and to estimate the overall extent of land cover classes in the region. This provided a general understanding about the study region, but a detailed investigation would be useful for bioregion to better understand land cover dynamics in a given year.

The long-term change analysis was carried out just for Brigalow Belt South (BBS) bioregion, as the amount of data used from 1972–2009, was enormous, and it was cumbersome and time consuming to handle such large volumes of data, especially in segmentation and classification verification processes. Similar efforts are needed for the remaining two bioregions. Nevertheless, the outcome of analysis for one bioregion was good enough to understand land cover changes in the region as a whole. Further, the data volume and processing time required in metric computation using FRAGSTAT with a number of land cover classes at patch, class and landscape level, restricted our study to two selected provinces in the of BBS bioregion. The shrinking spatial frame was incidental the study mostly focused on developing a new metric selection method and testing the capacity of selected metrics to highlight changes over time.

Finally, land cover change modeling, change predictions and habitat configuration analysis was carried out on only one province in the BBS bioregion. Again, the aim was to carry out detailed investigation of rather than assess an entire bioregions superficially. The model used was a first- order Markov chain, and since we used time series land cover data, there is scope for applying second or higher order Markov models for land cover change modeling in the future.

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