Modelling Greenhouse Gas Emissions from Land Cover Change: Linking Continental Data with Point/Patch Models

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Abstract: Australia, in compiling the annual National Greenhouse Gas Inventory, needs to account for emissions in the Inventory's Forests and Grasslands Conversion subsector resulting from land management activities since 1970. Clearing of land makes a significant but poorly quantified contribution to these emissions. Rates of land cover change (clearing and regrowth) since 1970 are currently being documented at the landscape scale from remotely sensed data. A method is presented using a 30 year one hectare level resolution data set to improve estimates of emissions from land clearing for the National Greenhouse Gas Inventory. The method is suitable for linking landscape scale disturbance histories derived from remotely sensed data to point or patch models of carbon fluxes to establish losses and gains of carbon continentally.

Keywords: Land cover change; Greenhouse gas emissions; Modelling;

1. INTRODUCTION

As a signatory to the United Nations Framework Convention on Climate Change, Australia prepares an inventory of its anthropogenic greenhouse gas emissions for its national report. Australia's National Greenhouse Gas Inventory is based on the internationally agreed methods developed by the Intergovernmental Panel on Climate Change, with some modifications to take into account conditions specific to Australia.

Land clearing, undertaken principally for agriculture, has contributed between 13 and 21 percent of Australia's net greenhouse gas emissions since 1990 [Australian Greenhouse Office, 2001a]. Emissions occur at the time of clearing and for some time after as woody biomass decays and soil carbon is lost. Quantification of emissions requires data on clearing undertaken since 1970, as well as spatially explicit information at appropriate scales for above and belowground biomass. Emission estimates are uncertain, since documentation of rates of land cover change has only been available continentally for the periods 1982-1990 [Graetz, 1998], 1990/91-1995 [Barson et al., 2000]. At the State level, data are also available for 1995-97 and 1997-1999 in Queensland [Queensland Department of Natural Resources, 1999a, b] and New South Wales [New South Wales Department of Land and Water Conservation 2001a, b]. A project currently underway, using Landsat Multi Spectral Scanner (MSS) and Thematic Mapper data (TM) will provide continental, spatially explicit land cover change information required to model greenhouse gas emissions from land clearing from 1970 to 2000 [Australian Greenhouse Office 2001b].

The challenge for continental scale carbon modelling is to link process-based point and patch models with data sets describing the high levels of heterogeneity in above and below ground carbon stocks, and detailed information on the drivers of change. This paper describes a method to link remote sensing data describing spatial and temporal changes over 30 years at the landscape level with patch scale models and carbon surfaces to produce estimates of greenhouse gas emissions following land clearing.

2. METHODS

2. 1 The Study Area

The Fitzroy Basin (Figure 1) in Central Queensland was chosen as the study area. This 14.25m ha area comprises extensively grazed Acacia and Eucalyptus woodlands; about 1.02m ha of more productive soils are cropped.

Comparison of 1780 land cover (derived from Queensland Herbarium vegetation data) with the Bureau of Rural Sciences' 1995 land cover data shows that around 54 percent of the catchment's woody vegetation (native vegetation ≥ 2 m tall and with a crown cover ≥ 20 percent) has been cleared since European settlement. Extensive clearing was initiated in the 1960s under the Brigalow Development Scheme. Clearing, principally for grazing, continued through the 1980s [Graetz, 1998] and 1990s [Barson et al., 2000; Queensland Department of Natural Resources, 1999a, b]. Increases in woody vegetation due to regrowth, even–aged regeneration of mostly native species, also occur on grazing land in this region where clearing has not removed all the rootstock.

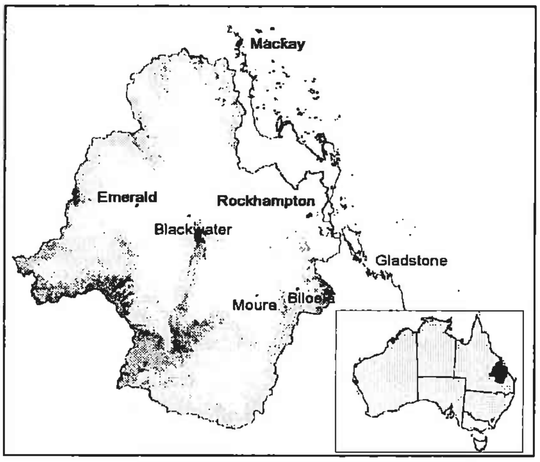

Figure 1. Location of the Fitzroy Basin.

2.2 Data Sources

An annual land cover history was established using the following:

- 1:100,000 and 1:250,000 scale topographic maps containing 8 classes of vegetation delineated from 1969-1988 aerial photography
- Landsat MSS 100 m data from 1982-84 and 1990-91
- 1991 25 m land cover, and land cover change data for 1991-95, 1995-97 and 1997-99 derived from TM imagery
- land use data at 1:100,000 scale for 1999
- native vegetation pre-clearing (c.1780) and extant (c.1995) at 1:100,000 scale.

Data Processing

Topographic maps were obtained from the Australian Surveying and Land Information Group as scanned images. Woody vegetation classes were captured using supervised classification and digitising; resultant data were converted into land cover classes:

- 0 unknown
- 1 crop/pasture
- 2 urban
- 3 bare
- 4 water
- 5 plantation
- 6 orchard
- 7 native woody vegetation.

The Landsat MSS data were supplied as a pair of satellite images (one from the early 1980s and the other from the 1990s). An analysis using the ISODATA algorithm was undertaken on the 8 bands from the combined images to generate 100 clusters; each cluster was classified into:

- land cover in early image
- land cover change (no change, increase or decrease in woody vegetation)
- land cover in later image
- cause (cropping, fire, cloud/shadow, clearing).

Land cover data for 1995, 1997 and 1999 were created by intersecting the 1991 land cover data derived from Landsat TM imagery with the 1991-95, 1995-97 and 1997-99 change data. All the data were converted to Arc/Info GRID format, projected into Albers Equal Area and resampled to 1 ha pixels. Figure 2 shows data coverage for the 73 1:100,000 mapsheets in the Basin for 1969-1999.

2.4 Developing the Land Cover History

Most land cover change studies undertaken to date have documented changes over one time interval, with spatial variability being the focus of interest. Calculating annual emissions from land clearing over the period 1970-1999 requires accounting for both spatial and temporal changes.

The approach adopted for this study builds on methods used to look at spatial and temporal changes in floristic data [Dale and Barson, 1989].

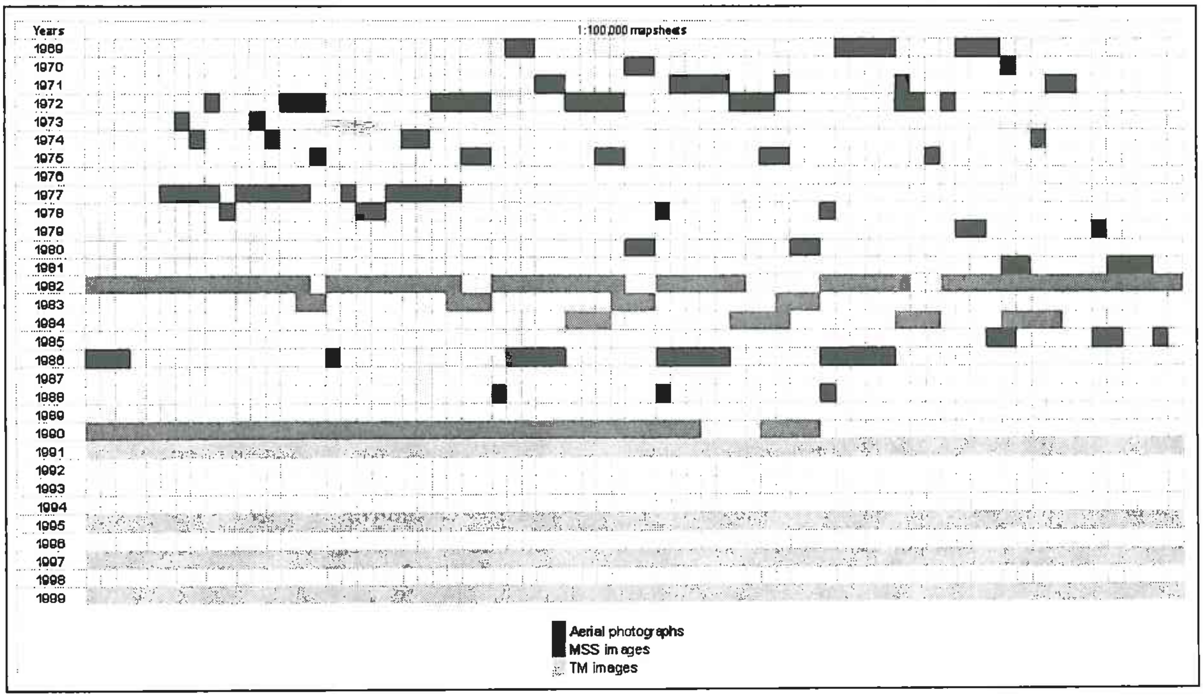

Figure 2. Spatial and temporal extent of land cover data.

Spatial elements of land cover change are tracked within the Geographic Information System. Dealing with temporal change involves:

- initial classification of the observational units, with pixels being assigned a land cover state (either woody, non woody or no data)
- organisation of these pixels into a string which describes their land cover status annually from 1969-1999
- establishment of rules for pixel behaviour.

These rules were that:

- there is a fixed probability p_i in any year that a wooded area will be cleared.
- an area cleared can potentially regenerate after five years.

Application of these rules plus calculation of conditional probability of change was used to fill data gaps (Figure 3). For example, if we had a gap in the string where the cover at time *i* and *j*, *i*>*j* were known, we simulated from Equation (1) where y_i is the observation at the *i*th time point. This is the conditional distribution of the missing data, given the status at the beginning and end of the string.

$$f(y_{i+1},\cdots,y_{j-1} \mid y_i, y_j) \qquad (1)$$

A land cover history was created by merging the annual land cover data and concatenating the annual codes into a string. The data were converted into a polygon coverage with each patch having an identical clearing history. Missing values were imputed for each patch with the gap-filling procedure, and the new string classified into a change class (Table 1).

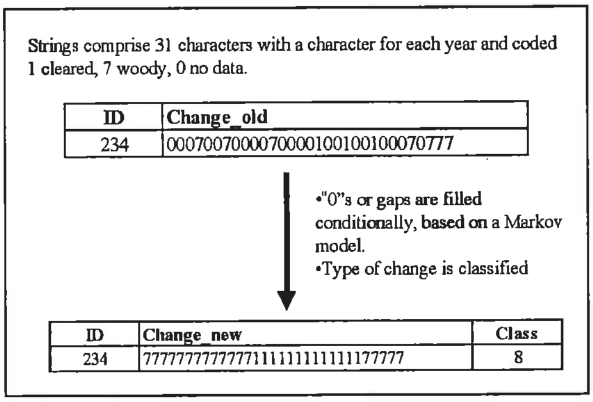

Figure 3. Filling data gaps in strings

Table 1. Classification of change classes

Class	Description	Example of codes
1	No change - cleared	1111111111111...
2	No change - woody	7777777777777...
3	Cleared once	7777771111111...
4	Regrowth once	1111777777777...
5	Cleared multiple	7771117777771...
6	Regrowth multiple	1111777771117...
7	Regrowth to cleared	1111177777771...
8	Cleared to regrowth	7777111111777...

Annual rates of clearing and regrowth were calculated from this data set. The cause of change (cropping, grazing, forestry, etc) was established from 1999 land use data, using the assumption (in the absence of better information) that clearing was undertaken to establish the current land use.

2.5 Linking the Land Cover History With Point/Patch Models

Our problem was constrained initially to look at net land clearing emissions using current National Greenhouse Gas Inventory assumptions that (1) 80 percent of carbon in aboveground vegetation is lost to the atmosphere in the year of clearing, (2) 10 percent (the slash left on the ground) decays linearly over a 10 year period, and (3) 10 percent remains on site as charcoal. (4) Thirty percent of belowground carbon (including root material) is lost from the top 30 cm of soil, decaying exponentially over 20 years (J. Kesteven, Australian Greenhouse Office, pers. comm.).

Combining the land cover history with high resolution above and below ground carbon data will improve the estimates of emissions following land clearing for the Fitzroy Basin. A more complete account of the carbon fluxes associated with land clearing will be developed by linking the land cover history with process models.

The soil carbon turnover model, RothC [Jenkinson, 1990], has been coded to run spatially. Annual input values for biomass can be derived from land cover status/vegetation type for each pixel in each year, and subsequently disaggregated to provide the monthly inputs required for the model. The next step is to develop a model to account for the gross changes in aboveground biomass due to land clearing which can be run spatially with high resolution land cover history data.

3. RESULTS

Figure 4 shows preliminary estimates of the annual rates of clearing and regrowth in the Fitzroy catchment. A total of 8.3m ha has been cleared over the 30 year period, and 4.1m ha has regrown over this time. These estimates include areas that were cleared and have regrown more than once.

Almost half of the clearing (4m ha) over the 1970 –1999 period was done by the end of the 1970s. Rates of clearing were considerably lower in the early 1980s, increasing through the late 1980s to 1990. After 1990 rates of clearing reduced sharply, and have averaged 58,000 ha annually since then. Some regrowth was detected in most years of the study, with higher rates in the 1980s. After 1991 very little regrowth was detected.

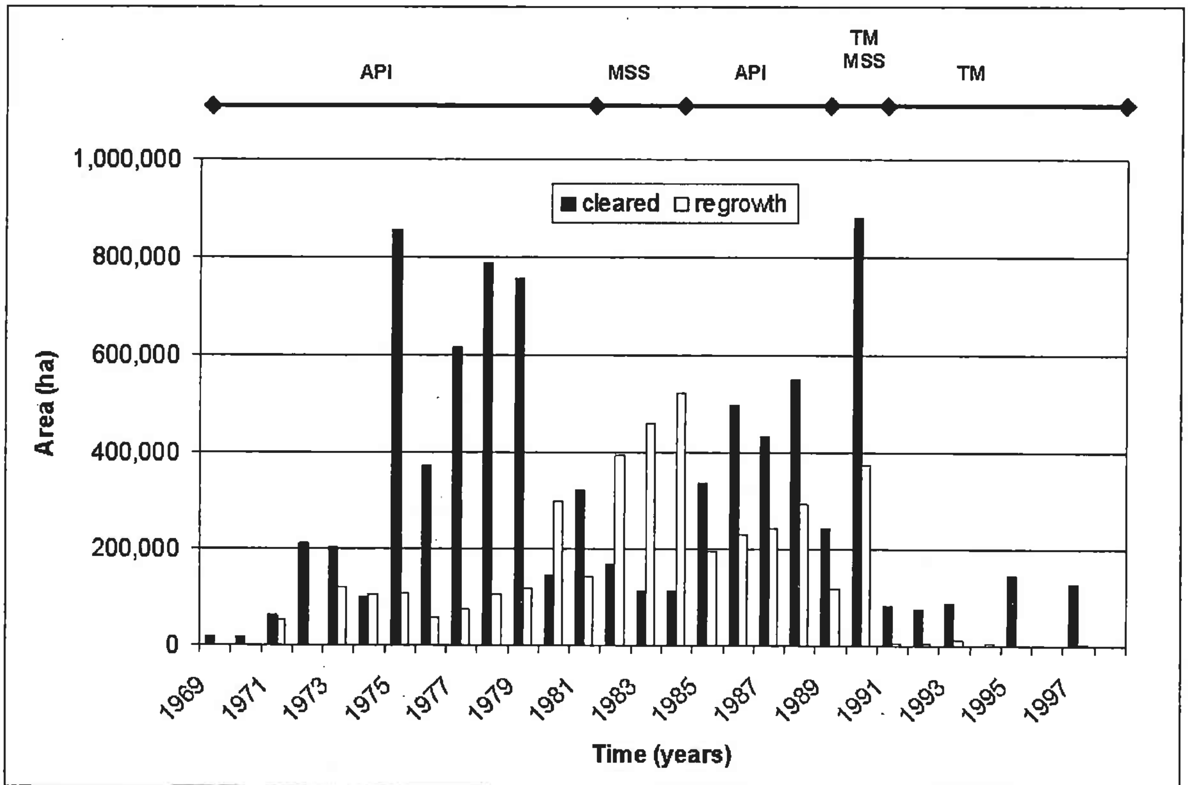

Figure 4. Annual rates of clearing and regrowth 1969-1999 (API aerial photograph interpretation; MSS Landsat Multispectral Scanner classification; TM Landsat Thematic Mapper classification).

Over the last 30 years, most of the clearing in the Fitzroy Basin has been to establish or maintain pastures (Table 2). About 6 percent of the clearing was for cropping; substantially smaller areas were harvested for forestry or cleared for plantations (2.6 percent). Small areas were cleared in conservation management areas (1.5 percent), for development of dams (0.1 percent) and for intensive uses such as urban development (0.3 percent).

It is likely that clearing in areas of conservation land use occurred prior to gazettal of their reserve status. Most of the regrowth has occurred on land used for grazing. Smaller areas of regrowth associated with forestry and conservation land uses are probably due to regeneration after forest harvesting or bushfires. Previous regrowth on land now used for cropping suggests that some of these areas were formerly grazed.

Table 2. Area of change 1969-1999 by land use.

	Area of change (ha)		
Land use	cleared	regrowth	multiple change
cropping	195,141	10,171	213,139
grazing	3,122,108	258,440	3,311,948
conservation	17,504	4,195	35,147
forestry	24,151	7,313	51,469
intensive uses	28,866	765	24,542
water	2,385	284	1,636
Total	**3,390,155**	**281,168**	**3,637,881**

Multiple changes involving several clearing and regrowth episodes occurred across 3.6m ha of the Basin. These sequences of clearing and regrowth occurred mostly on land used for grazing. The timing, location and types of vegetation that have regrown will be further investigated.

4. DISCUSSION

4.1 Land Cover History

Factors affecting the land cover history of the Fitzroy Basin since 1970 include development undertaken as a result of government policy decisions, commodity prices and changes in technology. The Brigalow Development Scheme proposed clearing of 1.7m ha of Acacia woodland in the Fitzroy [Bureau of Agricultural Economics 1962a, b]. Much of the clearing in the Fitzroy Basin was probably initiated under this scheme.

Movements in beef and wheat prices may have also influenced rates of clearing over the period 1970-1999. Wheat prices rose in 1973, and remained high. In 1999 1m ha were being cropped. Beef prices fell in 1974, and remained low until the 1990s [Australian Bureau of Agriculture and Resource Economics, 2000; Australian Bureau of Statistics, 1974-5, 1982-3, 1991-2, 1996-7]. Analysis of the rates of clearing over time by industry sector will be undertaken to examine the effect of commodity prices on clearing.

Clearing in the Fitzroy Basin in the 1960s and 1970s was done using tractors to pull chains through vegetation. Vegetation was usually heaped for burning several months later. Regrowth, particularly of brigalow, commonly occurred within 2-3 years, and further clearing was required. In the 1980s blade ploughing and the chemical, Graslan (tebuthiuron), were used to clear vegetation. The combined use of blade ploughing, (which turned the soil over to a depth of 25 cm) and chemical application inhibited regrowth. Improved clearing technologies, plus the dry climate across the Fitzroy for some years are likely to have reduced the rates of regrowth in the 1990s.

Estimates of clearing for 1991-1999 from this study were compared with those for the Fitzroy Basin 1991-95 [prepared from Barson et al 2000], 1995-97 and 1997-99 [prepared from Queensland Department of Natural Resources 2001a,b]. The method adopted for this study, comparison of annual land cover status to derive change, underestimated clearing by 10-20 percent. This may have resulted from the method used to calculate the conditional probability of clearing; further work is required to confirm this.

Graetz' [1998] data indicated that just over 1m ha were cleared in the Fitzroy Basin over the period 1982 – 1990. In contrast, our analysis, which used MSS imagery from the Graetz study, plus aerial photography, suggested that 2.45m ha were cleared over this period. Substantial regrowth (2.46m ha) was detected in the land cover history (1982-1990). The eight year time interval in the imagery used by Graetz, may have been sufficient for regrowth to have occurred by 1990 on areas cleared after 1982, resulting in an underestimate of the area cleared. Landsat TM data from a study of the rates of land clearing in Queensland 1988-91 being undertaken by the Queensland Department of Natural Resources and Mining will be available shortly, and will be used to refine the land clearing history for the late 1980s. When these data have been added to the land cover history, a number of sites in the Fitzroy Basin will be selected for.detailed study and field validation of their land cover history.

Three data sources, aerial photography, MSS and TM were used to develop the land cover history.

Further work is needed to examine differences in the detection of woody vegetation from these data. Land cover derived from aerial photography may overestimate the area of woody vegetation, since small gaps in the woody cover may be ignored in preparing the vegetation layer for topographic maps. Some of these problems will be overcome when the land cover data, derived from MSS for 1972, 1978, 1980, 1985, 1988 and TM for 1989, 1991, 1992, 1995, 1998 and 2000 being compiled for the Australian Greenhouse Office are completed.

4.2 Future Work

A number of sensitivity analyses are planned when the land cover history and improved biomass and soil carbon surfaces have been completed. These include investigation of the impact of changes to soil carbon loss parameters on emissions, and the impact of different land clearing practices on carbon fluxes. The land use history, when combined with data from the soil carbon surface and spatially explicit information on biomass production, will be used to drive the RothC soil carbon model. This will enable examination of the impact of land clearing and subsequent land use on soil carbon fluxes.

5. CONCLUSIONS

This study has outlined a method for constructing a high resolution land cover history suitable for application at the continental scale. Linking the land cover history with patch scale models will enable continental scale modelling of carbon fluxes. This application has been developed to investigate the impacts of land clearing. A similar approach could be applied to the estimation of carbon fluxes due to burning.

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