Clearing of native woody vegetation in the New South Wales northern wheatbelt: extent, rate of loss and implications for biodiversity conservation

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Clearing of native woody vegetation in the New South Wales northern wheatbelt was mapped for the period 1985–2000. The study area comprises the Moree 1: 250 000 scale map sheet and portions of adjacent map sheets. Unpublished draft mapping of native woody vegetation types, based on 1985 aerial photography and a large set of floristic data from field surveys, was used as a baseline for this study. Mapping of clearing was carried out by intensive visual interpretation of Landsat TM satellite imagery. Systematic validation, which compared the satellite interpretation to low-level aerial photography at randomly allocated point locations, showed that the method was highly accurate in detecting vegetation clearing including in the open woodlands and shrublands that characterise much of the study area. Comparisons with previously published mapping of statewide clearing patterns, based on an automated classification of Landsat TM imagery, showed that our intensive visual interpretation detected substantially more clearing. Average annual clearing rates were 8 times higher that those derived from the previous mapping.

Results of the study show that substantial clearing of native woody vegetation is continuing in the northern wheatbelt. Over 110 000 ha of native woody vegetation were cleared between 1985 and 2000. Clearing rates were highest in the four year monitoring period that preceded the introduction of the Native Vegetation Conservation Act. *The subsequent two year monitoring period saw substantially lower clearing rates, though further monitoring is needed to determine if this trend will continue. An analysis of spatial patterns highlighted continued high rates of loss in the most depleted parts of the study area. Results for individual vegetation types indicate that regrowth open shrublands and woodlands and Coolabah (*Eucalyptus coolabah*) dominated woodlands were the most heavily cleared.*

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Introduction

Temperate eucalypt woodlands are among the most poorly conserved and threatened ecosystems in Australia (Yates & Hobbs 2000). In the wheatbelt of Central New South Wales most of the original temperate woodlands have been cleared for agriculture over the last two hundred years (Benson 1999). What remains is mostly present as fragmented remnants which are subject to further threats such as weed invasion, altered fire regimes and overgrazing by domestic stock and feral animals (Fig. 1). The responses of biodiversity to the loss and fragmentation of native vegetation are complex and often difficult to predict in detail (e.g. Cunningham 2000) but the overall consequences of such drastic change are clear and include population and species extinctions and genetic loss (Saunders 1994, Ford et al. 1995, EPA 1997, Sivertsen & Clarke 2000). Population declines and extinctions would be expected to continue long after clearing had occurred, possibly for several centuries (Saunders et al. 1991, Tilman et al. 1994).

Extensive clearing in Central New South Wales has continued over the last three decades, in part driven by high returns available from wheat and cotton cultivation compared to grazing (Benson 1999, Beare et al. 1999). The area sown to cotton in New South Wales increased by approximately 80% between 1989 and 1997 (Bray 1999) while that for wheat increased by approximately 50% between 1992 and 1998 (Australian Bureau of Statistics, http://www.abs.gov.au). Sivertsen and Clarke (2000) present a summary of the area of woody vegetation in the New South Wales northern wheatbelt showing dramatic declines between the 1970s and 1980s with lower, though still substantial, declines between the 1980s and 1990s.

The recognition that native vegetation clearance is the single greatest threat to terrestrial biodiversity in New South Wales (EPA 2000) has prompted a number of legislative and policy responses. In 1995 State Environmental Planning Policy No. 46 on the protection and management of native vegetation was introduced as an attempt to prevent inappropriate land clearing. This was replaced by the *Native Vegetation Conservation (NVC) Act* which began operation in 1998 and sets out a system of regional vegetation management planning by local committees. In 2001 a preliminary determination was made to list clearing and fragmentation of native vegetation as a

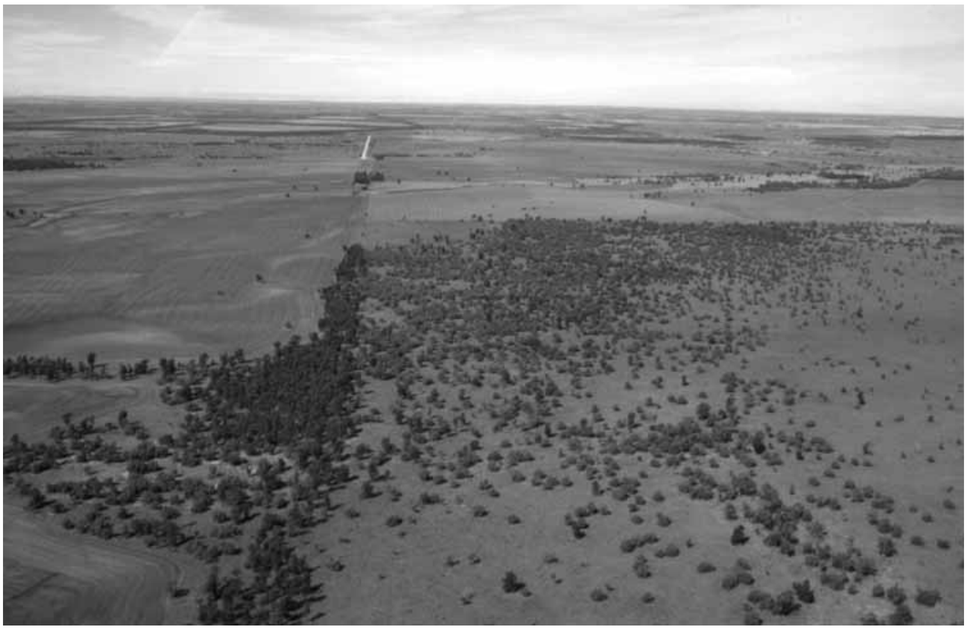

Fig. 1. A typical pattern of remaining native woody vegetation in the wheatbelt near Moree.

Key Threatening Process under the *New South Wales Threatened Species Conservation Act*. The determination lists impacts of clearing including the loss of habitat and species populations, expansion of dryland salinity, increased habitat for exotic species and increased greenhouse gas emissions.

Considering all of the above, it is alarming that there is little reliable, fine-scale information available on the distribution and extent of clearing in Central New South Wales. Some recent data are available on the total area of clearing applications that landholders submitted to the Department of Land and Water Conservation but interpretation of these data is difficult. Not all clearing requires approval under the *NVC Act* and clearing may not occur for up to 4 years after approval is granted. Some applications cover areas that have already been partially cleared and illegal clearing is obviously not included in the application data.

Precise and accurate remote sensing methods are required to monitor vegetation loss over an area as large as the wheatbelt. Large scale aerial photography is suitable but acquisition and interpretation is prohibitively expensive, especially for regular monitoring. Several studies have used satellite imagery to map the distribution of clearing. The New South Wales component of a national study by Barson et al. (2000) attempted to determine clearing rates from Landsat Thematic Mapper (TM) satellite data for the period 1991–95 using automated classification methods. This study only considered vegetation with an average tree canopy cover of at least 20% which excludes large areas of woodlands and shrublands with sparse cover (Benson 1999). Another study of Landsat TM data for the period 1995–97 (ERIC 1998) used an automated classification to identify areas of possible clearing followed by visual inspection of these areas. This study claimed to detect vegetation with a minimum tree canopy of 12–15% and found significantly higher rates of clearing than Barson et al. (2000). Although an improvement, the ERIC study still excluded many areas of sparse vegetation which will have high conservation significance. Sivertsen and Metcalfe (1995) mapped native woody vegetation in the southern wheatbelt with tree canopy cover down to 5%. The same threshold is being used for further mapping in the northern and central wheatbelt. Ideally, measurements of clearing would also consider vegetation down to this level of canopy cover.

Direct visual interpretation of satellite imagery is an alternative to automated classification methods and is supported by results from a number of local and overseas studies. Complex patterns involving irregular and diffuse boundaries are more reliably identified using visual interpretation and the human ability to assimilate shape, texture and spatial context is not yet matched by automated methods which only consider spectral information (Chuveico & Martinez Vega 1990, Kushwaha et al. 1994, Janssen & van der Wel 1994, Graetz et al. 1995). Hill and Kelly (1987) found Landsat TM satellite imagery more suitable for visual interpretation than other forms of analysis when considering semi-arid woodlands in southern Queensland. Milne and O'Neill (1989) commented that visual interpretation relies heavily on the skills of the observer and can be prone to inconsistency but they supported its use for identifying abrupt landcover changes such as vegetation clearing.

In this paper we present the first results of a study using visual interpretation of satellite imagery in comparison with available vegetation mapping and aerial photography. Our aims were:

- To measure the remaining extent and rate of loss of native woody vegetation with canopy cover down to 5% over a series of time intervals.
- To use available vegetation mapping to measure the area and rate of loss of vegetation types for each time interval.
- To measure the degree of fragmentation of native woody vegetation for each time interval.
- To identify trends in clearing, overall and for individual vegetation types, and speculate on driving factors and possible future trends.
- To compare the results of visual interpretation of satellite imagery to previous results from automated methods.
- To comment on implications for biodiversity conservation and identify needs for further monitoring and research.

Study Area

Location

The study area is the northern section of the NSW National Parks and Wildlife Service's wheatbelt vegetation mapping area (Fig. 2). It occupies approximately 2.4 million hectares and is bounded by the NSW state border to the north, the Western Division, the 30th parallel of latitude and by a line approximating the 300 metre contour interval to the east. It takes in the Moree 1: 250 000 scale map sheet and parts of the St. George, Goondiwindi, Angledool and Inverell map sheets. It includes the towns of Moree, Goondiwindi, Collarenebri, Rowena and Croppa Creek and the following Local Government Areas: Moree Plains (94% within the study area), Walgett (30%), Narrabri (15%), Yallaroi (13%) and Inverell (7%).

The study area encompasses portions of two important inland river systems, the Macintyre / Barwon and the Gwydir which form part of the Murray / Darling Drainage Basin. The Gingham Watercourse and Lower Gwydir Watercourse are identified as wetlands of international importance (ANCA 1996).

Topography, geology and soils

The predominant topographic feature of the study area is the low, flat to very gently undulating floodplains which are intermittently inundated by floodwaters. In the eastern section of the survey area isolated, low basalt hills and the sandstone footslopes of the Mastermans Range occur.

Much of the floodplains are Quaternary alluvium overlying sandstone, siltstone and claystone of the Rolling Downs Group from the Cretaceous Period (Chesnut 1968, Mond et al. 1968, Offenberg 1973). In the eastern section of the study area, the footslopes of the Mastermans Range are composed of Warialda sandstone formations from the Jurassic Period which form the basis of the shallow, sandy, low fertility soils (Chesnut 1968). Small isolated hills scattered in the east are intrusions of Tertiary basalt (Mond et al. 1968).

The major soil types can best be described as cracking clays of moderate fertility (Laut et al. 1980). Deep grey self-mulching clays dominate most of the study area as well as coarsely structured sandy clays. These soils have a moderate salt content 20–35 cm from the surface and are susceptible to water logging so that a small rise in the water table can cause salinity problems (Northcote 1979). Relic streamlines of residual Quaternary colluvial deposits provide a distinctive sandy red-brown duplex soil that supports quite different vegetation to the surrounding plains. Heavy textured brown and grey soils and black earths commonly display surface micro relief termed gilgai. Soil fertility is higher in the east than the west due to the rich basalt caps of the great dividing range (Morgan & Terrey 1992).

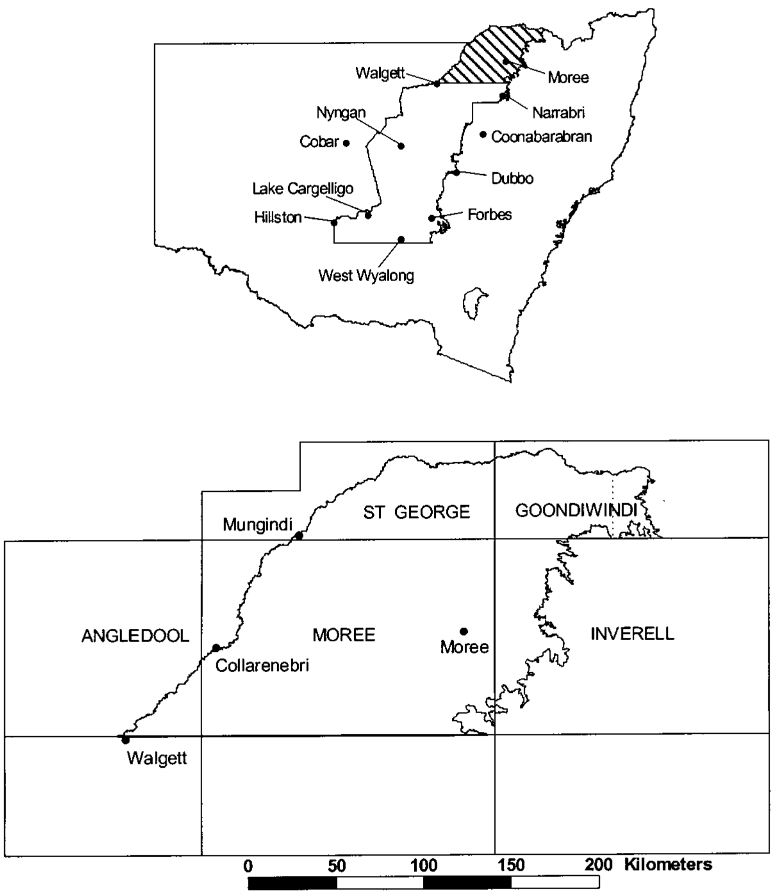

Fig. 2. The NSW National Parks and Wildlife Service wheatbelt vegetation mapping area (top) with the study area for this paper shown crosshatched. The 1: 250 000 scale map sheets covering the study area (bottom).

Morgan and Terrey (1992) identified three bioregional provinces within the study area (Fig. 3): Castlereagh-Barwon Province with extensive alluvial plains; Northern Outwash Province with low rises and alluvial fans; and Northern Basalts Province with gentle undulations and basalt capped hills. Two further provinces, Peel with fine grained hilly sediments and Northern Complex with sedimentary hills and ranges, occupy small areas on the eastern margin of the study area.

Climate

Average annual rainfall varies across the study area from 496 mm at Collarenebri in the west to 638 mm at Croppa Creek in the east (Bureau of Meteorology 1992). Rainfall occurs throughout the year with peaks in summer and autumn. The highest average rainfall is in the north-east of the study area while it becomes increasingly sporadic with lower average falls in the west. Evaporation rates are, on average, considerably higher than precipitation rates. Average temperatures range from 35°C in summer to 5°C in winter (Bureau of Meteorology 1992). Humidity is generally low and when combined with high temperatures the evaporation potential is greatly increased, resulting in a seasonal moisture deficit.

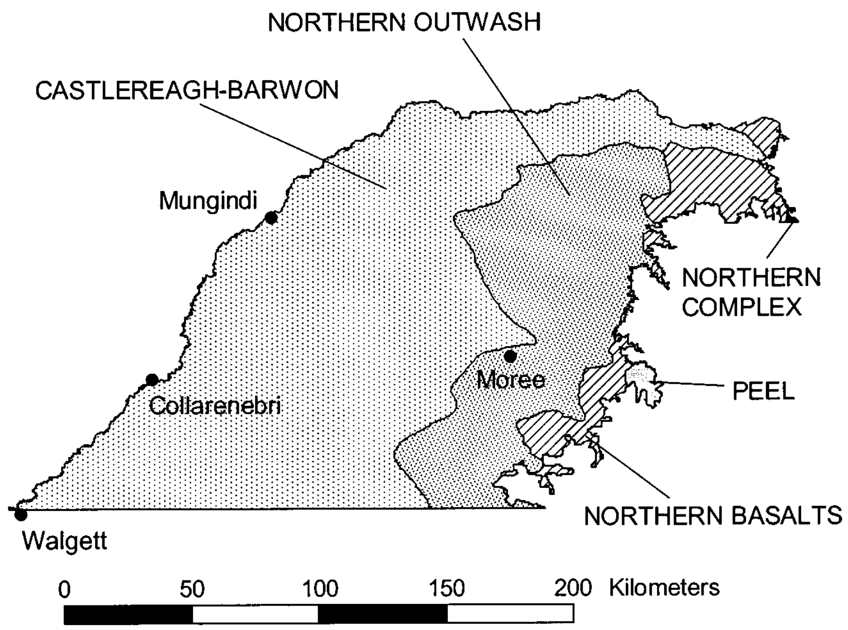

Fig. 3. Bioregional provinces of Morgan and Terrey (1992).

Vegetation

The study area was once a part of the continuous belt of temperate woodlands that ran from Queensland to Victoria (Beadle 1981, Sivertsen & Clarke 2000). Woodland types include savanna woodlands of River Red Gum (*Eucalyptus camaldulensis)*, Coolabah (*Eucalyptus coolabah*), Black Box (*Eucalyptus largiflorens*) and Brigalow (*Acacia harpophylla)*; shrub woodlands of Poplar Box (*Eucalyptus populnea* subsp. *bimbil)* and White Cypress Pine *(Callitris glaucophylla)*, Belah (*Casuarina cristata*) and Myall (*Acacia pendula*); Carbeen woodlands (*Corymbia tessellaris*) and box-ironbark woodlands of Poplar Box (*Eucalyptus populnea* subsp. *bimbil)* and Silver Ironbark (*Eucalyptus melanophloia*) (Beadle 1981, Sivertsen & Metcalfe unpublished). Lignum shrublands, wetlands and treeless grasslands are also found in the study area.

The native woody vegetation of the NSW wheatbelt has crown covers ranging from 5% to almost 100% (treating crowns as solid for the purpose of description) but is generally sparse over much of its extent (Sivertsen & Metcalfe 1995). Over half of the native woody vegetation mapped by Sivertsen & Metcalfe (unpublished) in the present study area ranges from scattered trees to open woodlands.

Landuse and Tenure

The flat plains and moderately fertile soils make the area very attractive for agricultural development (Laut et al. 1980). Over the past 50 years the main landuse for the Moree area had been pastoralism, with sheep dominating in the east and cattle in the west. Currently, the major landuses are grazing and cereal farming although the area of both irrigated and dryland cotton cultivation is increasing. The Moree area is the major region in NSW for crops and cattle and had the greatest wheat yield in tonnes per hectare from 768 000 ha sewn in 1997 (Bray 1999).

Most of the study area is in private ownership. Crown Land constitutes approximately 5% of the area. The only areas solely dedicated to conservation are five nature reserves: Boomi (156 ha), Boomi West (149 ha), Careunga (469 ha), Midkin (374 ha) and Boronga (195 ha). Together they occupy 0.05% of the study area. There are no State Forests in the study area.

Methods

Draft vegetation mapping for the northern wheatbelt (Sivertsen & Metcalfe unpublished) provided baseline data for this study. This mapping was derived from interpretation of 1985 aerial photography combined with multivariate analysis of field survey data following similar methods to Sivertsen and Metcalfe (1995). It defines 17 types of native woody vegetation (shrublands, woodlands and forests). Treeless native grasslands, highly modified native vegetation and areas with isolated scattered trees were not mapped. Some sedge dominated wetlands were mapped but these are omitted from the present analysis. Our baseline data are thus a subset of the native vegetation within the study area and hence our analysis of vegetation loss will be conservative.

The extent of clearing of native woody vegetation in 1994, 1998 and 2000 was derived from visual interpretation of Landsat TM satellite imagery (Table 1). We defined clearing as a change in canopy cover from greater than 5% to less than 5%. In addition, clearing was characterised on the images by the lack of near infra-red reflectance typical of vegetation, regular boundaries and more uniform texture and colour compared to adjacent areas of woody vegetation. Some sites with sparse tree cover, where the understorey is completely removed and replaced by cropping or fertilised pasture, will display a marked change in reflectance even though the canopy cover does not change. We treat such instances as clearing of native vegetation. We restricted our analysis to vegetation remnants with an area of at least 10 ha consistent with the limits of resolution of the satellite imagery and our methods.

For 1994 and 1998 we used hardcopy photographic images with 30 m × 30 m pixel size and bands 2 (visible), 4 (near infra-red) and 5 (mid infra-red). Clearing boundaries were drawn on a transparent overlay printed with the baseline vegetation mapping and fixed over each satellite image. The boundaries were then digitised. For the 2000 analysis we used Landsat digital data displayed with ERDAS Imagine 8.4 software on a UNIX workstation. The displayed images were visually interpreted and clearing boundaries were digitised directly on-screen. Inspection of aerial photographs for 1984/85 was used to assist with the interpretation of satellite images. Where an area had very sparse vegetation on the aerial photograph and it was difficult to determine whether it had been cleared from the satellite image the area was marked as uncertain.

There are a number of factors that contribute to uncertainty in interpretation. *Eucalyptus* and *Acacia* species and chenopods, common in most of the study area, have low reflectance at the near infra-red wavelengths used to distinguish vegetation and show little variation with substrate or seasonal change (Milne & O'Niell 1989). When vegetation is sparse, soil and bedrock are a dominant component of the spectral

Table 1. Landsat TM images used for the study.

Path	Row	Date	Map Sheets
90	80	2 Oct. 1998 14 Nov. 1999	Western Goondiwindi
91	80	17 Dec. 1994 20 Oct. 2000	St George, Goondiwindi, Northern Moree & Inverell
91	80	10 Apr. 1996	Northern Moree
91	80	10 Jan. 1998	St George, East Goondiwindi, Northern Moree and Inverell
91	81	17 Dec. 1994 20 Oct. 2000	Southern Moree & Southern Inverell
91	81	9 Mar. 1996	Southern Moree
91	81	12 Dec. 1998	Southern Moree & Southern Inverell
92	80	14 Mar. 1995 22 Mar. 1998 14 Dec. 2000	Angledool & South West Moree
92	80	22 Mar. 1998	Angledool & South West Moree

information. Soils with either very high or very low reflectance will narrow the range of spectral information. These factors make it more difficult to distinguish between the presence and absence of sparse woody vegetation.

We assessed the accuracy of the visual interpretation procedure using additional 1996 Landsat imagery and 1: 50 000 scale aerial photography, both of which were available for the Moree 1: 250 000 scale map sheet. The satellite images were interpreted using the methods described above. Next, random point locations were selected within the area covered by five runs of the aerial photographs such that there were 60 points in the newly cleared category and 100 points in the no change category. Each point in the cleared category was then accurately plotted onto the corresponding 1996 aerial photograph to check for errors in identifying clearing. The points in the no change category were plotted onto both the 1996 and 1985 photographs to check for errors in identifying no change. For the 1998 analysis, an accuracy assessment was carried out using the same method with specially flown 1: 16 000 scale aerial photography.

We assessed the allocation of the uncertain category in our satellite image interpretation with a similar procedure. 60 random point locations were selected from uncertain areas on the 1996 Landsat imagery and checked on the corresponding aerial photographs. For the 1994 interpretation we carried out aerial inspections of all uncertain areas and allocated them to either cleared or no change. This was not possible for 1998 or 2000 and we have excluded the uncertain category from the measurement of vegetation clearing presented here. As such our results are conservative.

We compared the results of our visual interpretation method with previously published data derived from an automated classification of Landsat imagery. These data accompanied a report on vegetation clearing in New South Wales, for the period 1995 to 1997, commissioned by the NSW Department of Land and Water Conservation (ERIC 1998). We compared the extent and location of clearing identified in the ERIC study for 1995 to 1997 to our results for the period 1994 to 1998.

Analyses of the mapped data were carried out using ArcView software. For the baseline 1985 mapping and each of the 1994, 1998 and 2000 coverages we measured the total area of native woody vegetation and the area of each of the vegetation types of Sivertsen and Metcalfe (unpublished). For 1994, 1998 and 2000 we calculated the following statistics for total native woody vegetation and each vegetation type:

- area cleared since the last measurement date;
- area remaining as a percentage of the 1985 extent;
- average annual clearing rate (hectares per year);
- average annual clearing rate as a percentage of the 1985 area;
- average annual clearing rate as a percentage of the area at the last measurement date.

The study area straddles Australian Map Grid Zones 55 and 56. The total area measurements for native woody vegetation were carried out for each map zone independently and the results combined to avoid distortions from reprojecting the data which would be in the order of about 1% overestimation. For measurements of individual remnant areas (see below) and the area of individual vegetation types we reprojected the smaller zone 56 portion of the study area into zone 55 to produce a combined coverage.

For a preliminary assessment of fragmentation of remaining native woody vegetation we calculated the following statistics for total native woody vegetation and each vegetation type.

Number of patches

For overall vegetation this is the number of distinct remnants in the study area. Clearing can lead to both a decrease in this number, through the loss of remnants, and an increase, through the splitting of previously intact patches into new separate patches (Fig. 4). For this reason the number of patches must be interpreted in conjunction with changes in total area. For vegetation types the number of patches means the number of spatially distinct stands of a given type. This is not the same as the number of remnants since stands can be surrounded by other types of native woody vegetation and more than one stand of a type can occur within a single vegetation remnant. But following the number of patches of a vegetation type over time in conjunction with the total area of that type gives an indication of the degree to which its distribution is becoming fragmented.

Minimum, median and maximum patch area

For overall vegetation these statistics relate to the area of spatially distinct remnants. Clearing can lead to both an increase in minimum patch area, through the loss of the previously smallest remnants, or a decrease, through the subdivision of existing remnants (Fig. 4). As mentioned previously, the lower limit for patch area in this study was 10 ha. We have reported on median rather than average areas because of the often highly skewed distribution of area values. For vegetation types the patch area statistics refer to spatially distinct stands of a given type. The minimum patch area for types can vary in either direction as for overall vegetation. Note that the minimum patch area for a vegetation type may be less than 10 ha where the patch is part of a larger vegetation remnant.

Median perimeter to area ratio for patches

Perimeter to area ratio gives some indication of the vulnerability of a patch of vegetation to edge effects and relates to both the size and shape of a patch (Fig. 5). For overall vegetation we calculated the ratio of the total perimeter length of a vegetation remnant to its area. For vegetation types we only consider that part of the perimeter that is adjacent to cleared land (Fig. 6). Accordingly we report on the number of patches that are immediately adjacent to cleared land and it is only these patches that are included in the calculations. To account for the boundary of the study area we masked out those sections of patch perimeters that lay on the boundary.

Size distribution of patches

To further illustrate trends in the sizes of vegetation remnants and patches of individual vegetation types we present histograms showing the percentage of remnants or patches in different size classes. Note that our present analysis of fragmentation is preliminary. A comprehensive assessment would also consider the spatial arrangement of vegetation, condition and disturbance attributes, the requirements and distribution of particular plant and animal taxa, and the interaction between these various elements.

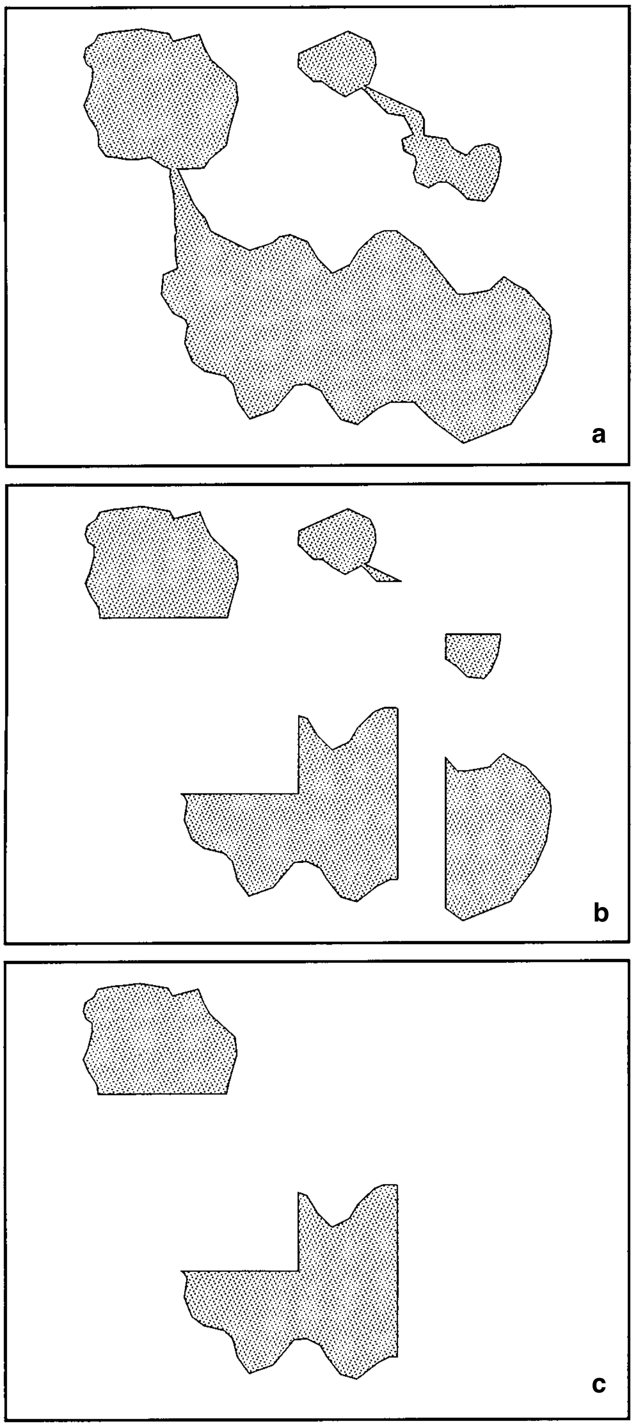

Fig. 4. Change in the number of remnants and the minimum remnant size with clearing. Initially there are two remnants (a). A clearing event leads to an increase in the number of remnants and a decrease in minimum remnant area (b). A further clearing event leads to a decrease in the number of remnants and an increase in minimum remnant area (c).

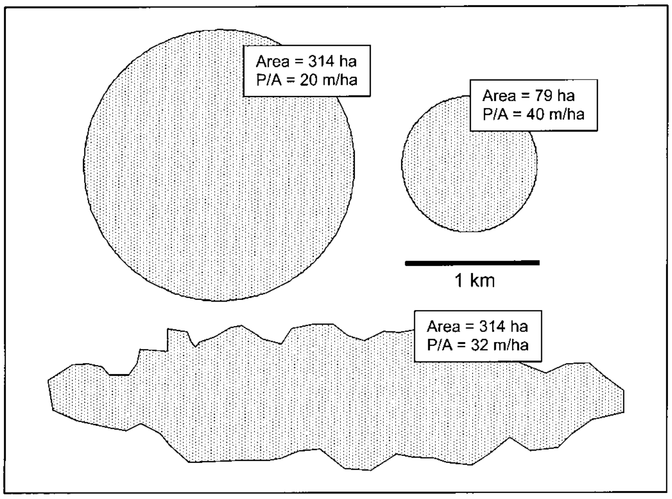

Fig. 5. Illustration of perimeter to area ratio (values are in metres per hectare). The large circle has the smallest ratio of perimeter to area (P/A) of the three features, i.e. it has the least proportion of its area near the edge. The irregular feature has the same area as the large circle but a higher P/A value due to its longer perimeter. The small circle has the highest P/A value, i.e. the most proportion of area near the edge.

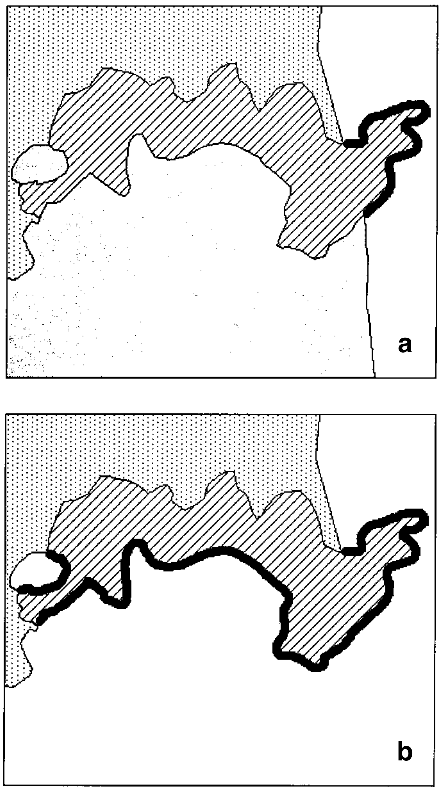

Fig. 6. The length of the exposed perimeter (bold line) for the cross-hatched vegetation type (a) increases after a clearing event (b).

Results

Accuracy and bias assessment

The comparison of 1996 satellite image interpretations and aerial photography for the Moree 1: 250 000 scale map sheet gave an overall accuracy of 96.8% (Table 2). For 1998 the same comparison gave an overall accuracy of 94.7% (Table 3). We conclude that our methods reliably and consistently distinguish recent clearing and areas of no change.

In the comparison of the uncertain category on the 1996 satellite imagery with aerial photographs (Table 4), 19 (32%) of the 60 validation points were in recently cleared vegetation. The uncertain category represents areas with very sparse vegetation at the lower end of resolution for our method. But our results indicate that the uncertain category is informative and, if resources were available, field or aerial inspections of areas in this category would detect further clearing. As stated previously, the uncertain category has been excluded from our analyses of the 1998 and 2000 interpretation. The total area mapped as uncertain was 17 822 ha for 1998 and 7531 ha for 2000.

Table 2. Accuracy assessment of 1996 satellite image interpretation for the Moree 1: 250 000 scale map sheet. Areas of recent clearing and no change were delineated on aerial photographs and randomly located points within these areas were compared to the satellite image interpretation.

	Aerial photography	
	Cleared	**No change**
Total number of points	60	100
Number mapped as cleared from satellite imagery	56	1
Number mapped as no change from satellite imagery	4	99
% accuracy	93.3	99.0
Overall accuracy (total correct/total points) 96.8%		

Table 3. Accuracy assessment of 1998 satellite image interpretation for the Moree 1: 250 000 scale map sheet. Areas of recent clearing and no change were delineated on aerial photographs and randomly located points within these areas were compared to the satellite image interpretation.

	Aerial photography	
	Cleared	**No change**
Total number of points	57	95
Number mapped as cleared from satellite imagery	54	5
Number mapped as no change from satellite imagery	3	90
% accuracy	94.7	94.7
Overall accuracy (total correct/total points) 94.7%		

Table 4. Examination of areas mapped as uncertain in the 1996 satellite image interpretation for the Moree 1: 250 000 scale map sheet. 60 random point locations within uncertain areas were checked for clearing on aerial photographs.

	Aerial photography	
	Cleared	**No change**
Satellite image interpretation uncertain	19 (32%)	41 (68%)

Results for overall native woody vegetation

Figure 7 shows the extant native woody vegetation at the beginning of the study period in 1985. Its total area was 661 238 ha, representing 27.3% of the study area. There was a strong correlation between the distribution of the remaining vegetation and the bioregional provinces of Morgan and Terrey (1992) with the eastern provinces having already been very extensively cleared.

Clearing

Over 110 000 ha of native woody vegetation were cleared between 1985 and 2000 representing over 16% of the 1985 baseline vegetation mapping (Table 5). Average clearing rates differed markedly between the different measurement periods with the highest rate, in excess of 10 000 ha per year, recorded in the period ending 1998 (Fig. 8). The subsequent period, ending 2000, saw the clearing rate drop to approximately one third that of the preceding period. Figure 9 shows all clearing detected during the study period.

Fragmentation

In addition to the substantial reduction in area, the remaining native woody vegetation became increasingly fragmented over the study period. The number of remnants has steadily increased (Table 5) as formerly contiguous vegetation has been split by clearing. The effect of this creation of new remnants outweighed the complete clearing of other remnants which we observed. Note that the largest remnant size for all monitoring periods is over 200 000 hectares. A large proportion of the vegetation in the western part of the study area is inter-connected. Although some of the connections are very narrow, the whole of the connected portion is treated as a single remnant under our criterion of remnants being spatially distinct.

The results for median remnant area and perimeter to area ratio show that the vegetation is being successively reduced to smaller and more exposed fragments. The percentage of remnants with areas of 100 ha or less increased at the expense of remnants in larger size classes (Fig. 10).

Spatial patterns

In general the density of clearing across the study area reflects the density of vegetation at the beginning of the study period and most clearing occurred in the Castlereagh-Barwon province (Fig. 7 and Fig. 9). Particularly large areas were cleared to the east of Collarenebri and Mungindi. The major bioregional provinces in the eastern half of the study area, Northern Outwash and Northern Basalts, were extensively cleared during the 1970s and earlier. Table 6 shows the extent and percentage of native woody vegetation in these three provinces for each monitoring period.

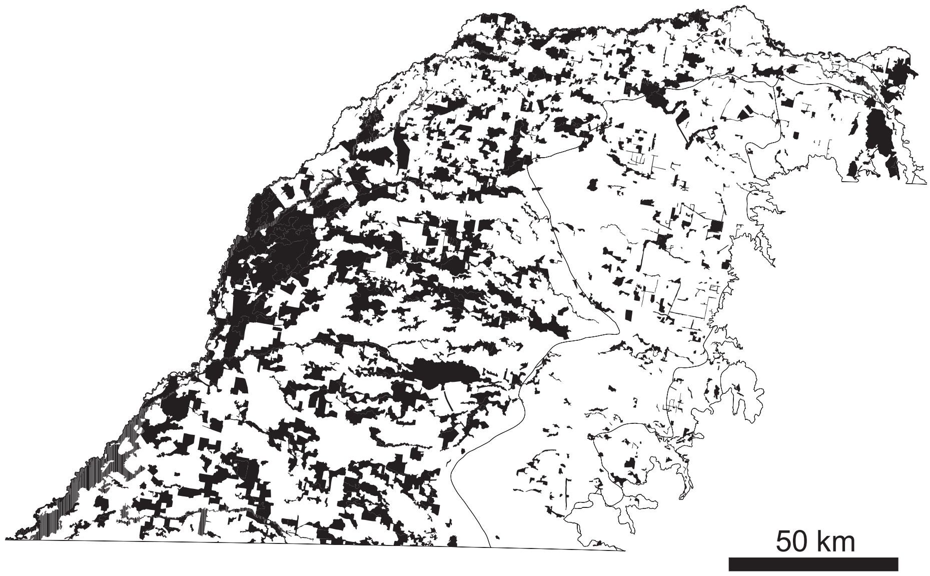

Fig. 7. The distribution of native woody vegetation at the start of the study period. Lines indicate the boundaries of bioregional provinces.

Table 5. Results for overall native woody vegetation

	1985	1994	1998	2000	Overall
Extant vegetation (ha) (% study area)	661 238 (27.3%)	600 721 (24.8%)	557 945 (23.1%)	550 911 (22.8%)	
Area cleared (ha)	-	60 517	42 776	7034	**110 327**
Area cleared (% 1985 vegetation)	-	9.2%	6.5%	1.1%	**16.7%**
Average annual clearing rate (ha/yr)	-	6724	10 694	3517	**7355**
Average annual clearing rate (as % 1985 vegetation)	-	1.02%	1.62%	0.59%	**1.1%**
Average annual clearing rate (as % previous area)	-	1.02%	1.78%	0.63%	
Number of patches	535	588	665	684	
Median patch area (ha) (min–max)	141 (11–281 564)	120 (10–242 030)	102 (10–214 617)	95 95(10–212 297)	
Median P/A ratio (m/ha)	55.5	60.0	64.1	66.3	

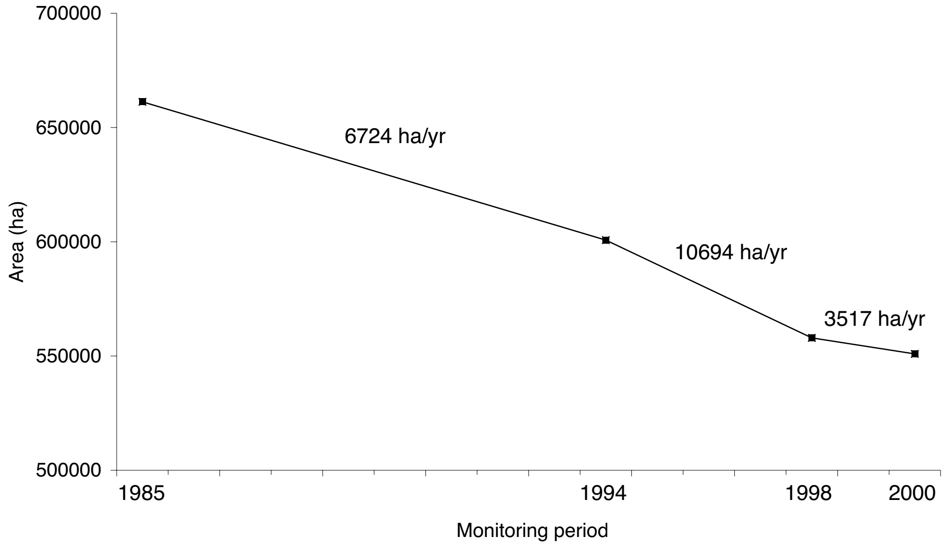

Fig. 8. Change in the area of native woody vegetation over the study period with average clearing rates shown for each monitoring interval.

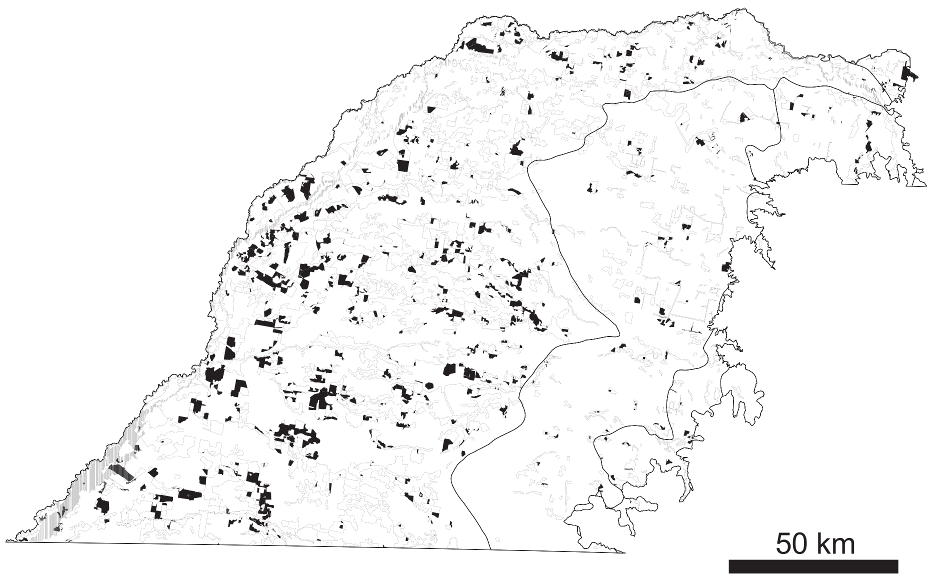

Fig. 9. The distribution of all clearing detected over the study period. Lines indicate the boundaries of bioregional provinces.

Table 6. The extent of native woody vegetation in the major bioregional provinces of Morgan and Terrey (1992).

	Area of native woody vegetation (ha and as % of province area)			
Province	**1985**	**1994**	**1998**	**2000**
Castlereagh-Barwon	579 390 (36.54%)	525 548 (33.14%)	484 654 (30.57%)	478 733 (30.19%)
Northern Outwash	50 813 (8.08%)	47 700 (7.59%)	45 811 (7.29%)	44 760 (7.12%)
Northern Basalts	31 779 (16.97%)	28 081 (15.00%)	27 501 (14.69%)	27 301 (14.58%)

Relative impacts

The pattern of relative clearing impacts is more complex than a simple east-west gradient as shown in Fig. 11. This map was derived from overlaying a regular 1 km grid of points onto the study area and calculating the percentage of native woody vegetation that was cleared throughout the study period within a 10km radius of each point. It highlights areas in the eastern portion of the study area where small clearing events have had a high relative impact. For example, north-east of Moree, where native woody vegetation was already highly depleted in 1985, further clearing resulted in losses of over 40%.

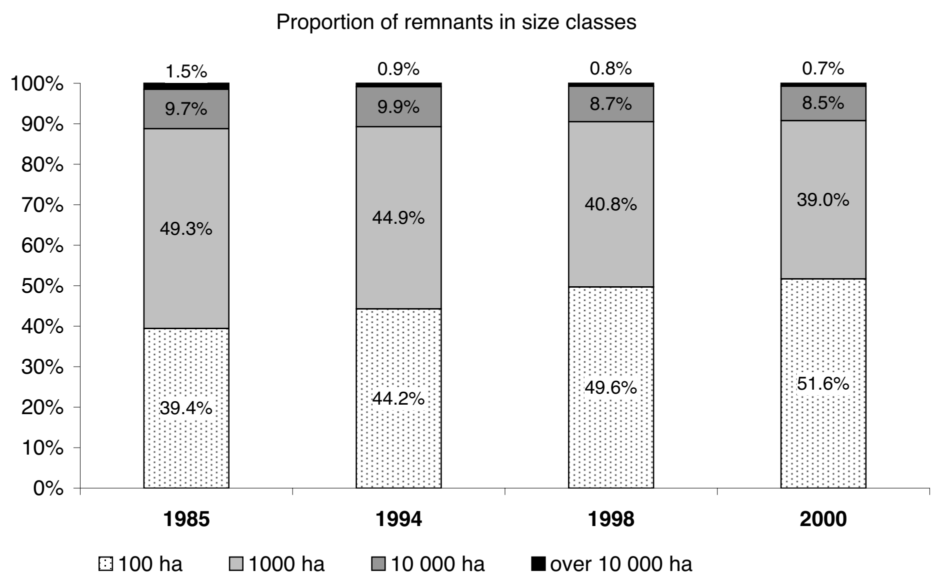

Fig. 10. Individual remnant areas over the study period expressed as the percentage of remnants in each of four size classes.

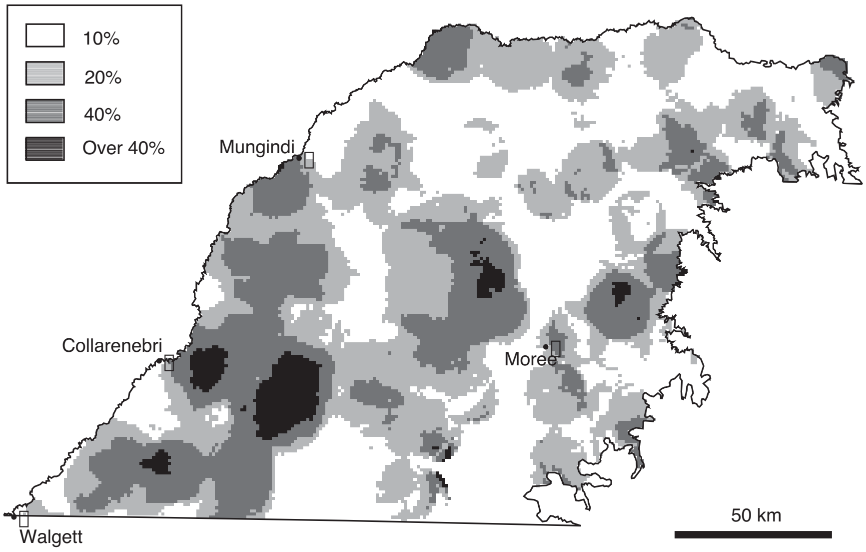

Fig. 11. The relative impact of clearing across the study area during the study period expressed as the percentage of native woody vegetation cleared within a 10 km radius.

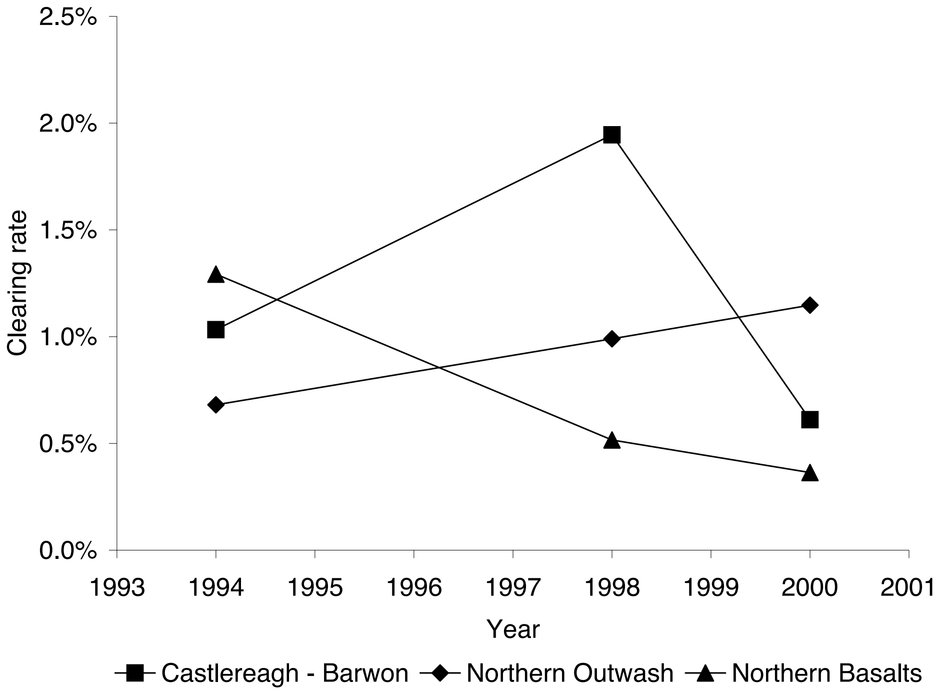

Fig. 12. Average annual clearing rates for native woody vegetation within bioregional provinces.

There were differing relative impacts for bioregional provinces, in terms of rates of percentage loss of vegetation (Fig. 12). The graph shows the average annual percentage of extant vegetation cleared during each monitoring period. Clearing rates in the western province, Castlereagh-Barwon, and eastern province, Northern Basalts, were at their lowest level in the last monitoring period ending 2000. In contrast, clearing rates for Northern Outwash province steadily increased over the study period.

Results for vegetation types

Descriptions and detailed results for each of the types of native woody vegetation mapped by Sivertsen and Metcalfe (unpublished) are listed in the Appendix.

Table 7 summarises the overall results by vegetation type ranked by the percentage of 1985 extent cleared. The greatest percentage loss occurred in Type R4: Lignum Shrublands, but given its small total extent and the difficulty in mapping this type (see Appendix) this is less significant than results for other types. The percentage loss for four extensive vegetation types exceeded the overall rate of vegetation loss for the study period. Only one vegetation type had no clearing detected during the study period.

The total percentage cleared versus 1985 extent for vegetation types is shown in Fig. 13. Vegetation types have been grouped on the basis of similar clearing versus extent values. Each of these groups is discussed below.

Group 1: Very extensive and heavily cleared

This group has one member, Type P9: Open Shrublands and Woodlands, which is defined by Sivertsen and Metcalfe (unpublished) as regrowth vegetation of various ages (see Appendix). Most of its distribution is in the Castlereagh-Barwon bioregional province. Fig. 14 shows the extant vegetation for 2000 together with vegetation that was cleared during the study period. Type P9 accounted for 28% of the native woody vegetation in the study area in 1985.

The open nature of Open Shrublands and Woodlands and large component of relatively young regrowth vegetation (see Appendix) probably makes it relatively easy and inexpensive to clear. It is also possible that there is a perception that, as regrowth vegetation with obvious signs of previous disturbance, it is of low value (Fig. 15).

The *NSW Native Vegetation Conservation Act* currently allows the clearing of regrowth vegetation that is up 10 years old without approval. However the definition of regrowth is open to interpretation since there are no definitions in the Act for the terms used in this particular exemption. Further the Act does not specify how to determine the age of vegetation or what components (trees, shrubs, grasses) should be considered. This and other exemptions for clearing under the Act are currently being reviewed by the New South Wales Government.

Group 2: Extensive and heavily cleared

Four vegetation types are in this group: R2: Floodplain Mosaic, R3: Coolabah Woodlands, R7: Coolabah-Poplar Box Woodlands, and R10: Open Coolabah

Table 7. Summary of the extent and rate of clearing for vegetation types arranged in decreasing order of proportional loss. The horizontal line indicates the general percentage rate of vegetation loss over the study period. The overall values (bottom row) are derived from the analysis of data for separate AMG map zones as described in the Methods and presented in Table 5. The values for vegetation types are derived from the analysis of data merged into AMG Zone 55.

Vegetation type	1985 area (ha)	Area cleared (ha) (ha/yr)	Percentage of 1985 area	Average clearing rate (ha/yr)	Average clearing rate (% 1985 area)
R4: Lignum Shrublands	1212	357	29.5%	24	1.96%
P9: Open Shrublands and Woodlands	186 604	41 875	22.4%	2792	1.50%
R2: Floodplain Mosaic	71 586	13 948	19.5%	930	1.30%
R10: Open Coolabah Woodlands	86 689	16 314	18.8%	1088	1.25%
P3: Open Poplar Box Woodlands	21 954	4085	18.6%	272	1.24%
P8: Belah Woodlands	12 172	1988	16.3%	133	1.09%
R3: Coolabah Woodlands	86 064	12 514	14.5%	834	0.97%
P10: Brigalow Woodlands	5792	823	14.2%	55	0.95%
H5: Yetman Hills Complex	17 201	2422	14.1%	161	0.94%
R7: Coolabah-Poplar Box Woodlands	93 935	11 679	12.4%	779	0.83%
R8: White Cypress Pine-Carbeen Woodlands	16 521	1970	11.9%	131	0.80%
R5: Myall Woodlands	8466	839	9.9%	56	0.66%
P4: Poplar Box Woodlands	11 205	1097	9.8%	73	0.65%
H8: Basalt Hills	1649	146	8.9%	10	0.59%
F4: Yetman Footslopes Complex	697	19	2.8%	1	0.19%
R1: River Red Gum-Coolabah Forests	39 415	455	1.2%	30	0.08%
P6: Iron Bark-White Cypress Pine Woodlands	132	0	0.0%	0	0.00%
Overall	**661 238**	**110 327**	**16.7%**	**7355**	**1.1%**

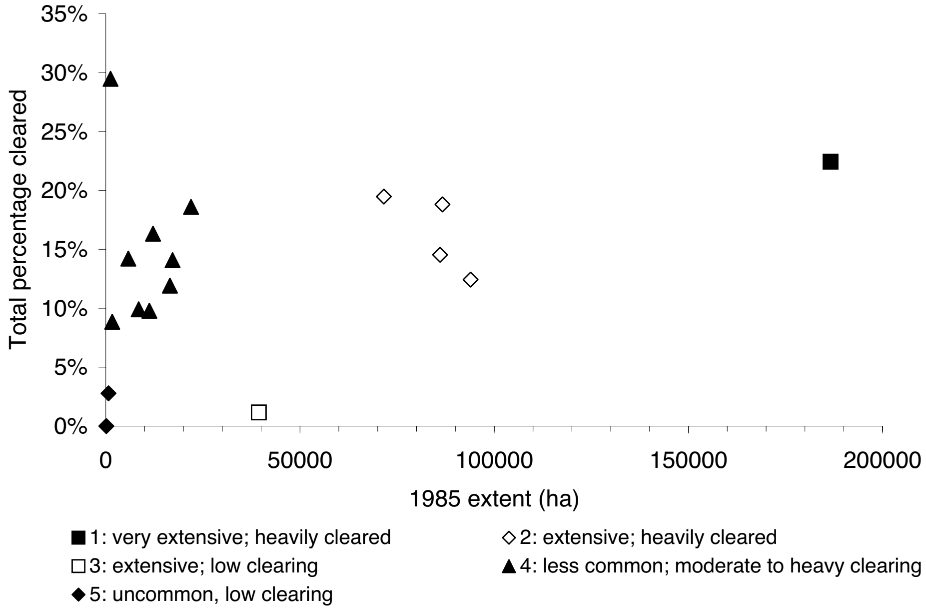

Fig. 13. Relationship between the percentage cleared and 1985 area for vegetation types. Groupings are referred to in the text.

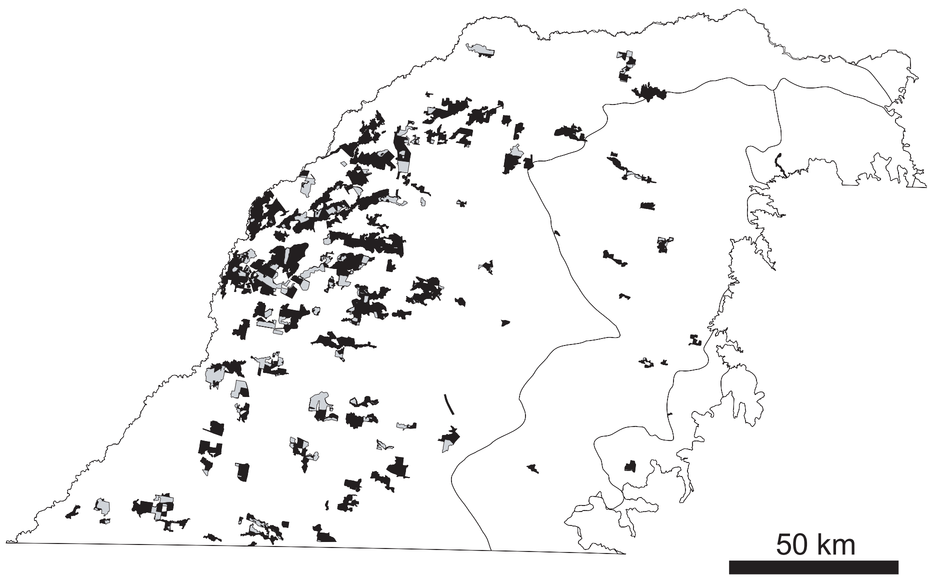

Fig. 14. Vegetation group 1: very extensive and heavily cleared (see text). Grey areas indicate clearing during the study period. Black areas indicate extant vegetation at the end of the study period. Lines indicate the boundaries of bioregional provinces (Fig. 3).

Fig. 15. Stand of vegetation type P9: Open Shrublands and Woodlands with young regeneration in the foreground.

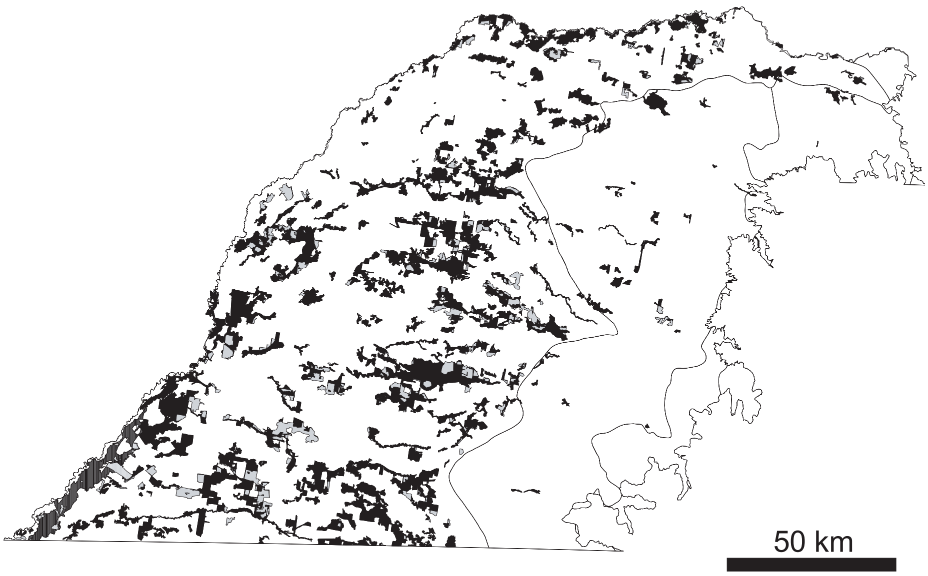

Fig. 16. Vegetation group 2: extensive and heavily cleared (see text). Grey areas indicate clearing during the study period. Black areas indicate extant vegetation at the end of the study period. Lines indicate the boundaries of bioregional provinces (Fig. 3).

Woodlands. They are mostly found in the Castlereagh-Barwon bioregional province (Fig. 16). This group accounted for 50% of the native woody vegetation in the study area in 1985. Coolabah (*Eucalyptus coolabah*) is the most common canopy species in these four vegetation types (Fig. 17).

The vegetation types in this group are found on grey clay soils that are suitable for cultivation and the low relief of the Castlereagh-Barwon province means that there are no physical constraints to prevent clearing. Substantial clearing of this group has occurred on and around the Gwydir Raft, west of the Moree township.

Group 3: Extensive with a low level of clearing

Only one extensive vegetation type, R1: River Red Gum-Coolabah Forests, experienced low levels of clearing during the study period. It is generally restricted to narrow bands in close proximity to rivers (Fig. 18) though in some areas its pre-European distribution would have included broader areas of adjacent floodplains.

Clearing within 20 metres of a watercourse has been prohibited since 1938 under the *Soil Conservation Act,* and continues to be prohibited under the *Native Vegetation Conservation Act*.

Group 4: Less common with a low to moderate level of clearing

Nine vegetation types are in this group: R4: Lignum Shrublands, R5: Myall Woodlands, R8: White Cypress Pine-Carbeen Woodlands, P3: Open Poplar Box Woodlands, P4: Poplar Box Woodlands, P8: Belah Woodlands, P10: Brigalow Woodlands, H5: Yetman Hills Complex, and H8: Basalt Hills. In general they occur in the eastern part of the study area which was very extensively cleared prior to 1985

Fig. 17. Stand of *Eucalyptus coolabah.*

(Fig. 19). Type R8 corresponds to Open Carbeen Forest which was listed as an Endangered Ecological Community under the auspices of the *NSW Threatened Species Conservation Act* in 1999.

This group typically occupies earthy loams and brown and grey clays which are suitable for agriculture. It is also found on sandy lenses which have only recently become suitable for cultivation with the development of new methods to seal the sandy soil with clay for flood irrigation.

Group 5: Uncommon and low level of clearing

This group is made up of two vegetation types, P6: Iron Bark-White Cypress Pine Woodlands and F4: Yetman Hills Complex. Both are very uncommon in the study area with a combined extent of less than 1000 ha in 1985.

Comparison with previously published results

Mapping undertaken by ERIC (1998) identified 2714 ha of clearing within the present study area for the period 1995 to 1997. Taking this as a 2-year period gives an average clearing rate of 1357 ha per year. In comparison, our mapping identified 42 776 ha of clearing for the period 1994 to 1998. Taking this as a 4-year period gives an average clearing rate of 10 694 ha per year, about 8 times the rate reported by ERIC (1998). Given the demonstrated accuracy of our visual interpretation methods, the extent, and hence the rate, of clearing reported by ERIC (1998) is clearly a significant underestimate for the study area.

Discussion

Native vegetation clearance is the single greatest threat to terrestrial biodiversity in New South Wales (EPA 2000). Continued clearing also threatens future agricultural production and incomes for farms and local communities through increased salinity, soil erosion, loss of insect pollinators, loss of native predators of agricultural pests, and disruption to other ecological services.

Our results show that substantial clearing of native woody vegetation is continuing in the northern New South Wales wheatbelt. Over the study period from 1985 to 2000 more than 110 000 ha of woody vegetation, 16.7% of the mapped 1985 extent, was cleared. Although the overall rate of clearing, and the rates for most individual vegetation types, were lower in the final 1998–2000 monitoring period than in the preceding period, clearing still exceeded 7000 ha (Table 5). In the most highly depleted bioregional province, Northern Outwash, the clearing rate steadily increased over the study period despite the province having only 8% native woody vegetation cover in 1985 (Fig. 12, Table 6).

Figure 20 shows simple projections of loss for native woody vegetation based on the overall average annual clearing rate and the rates for the last two monitoring periods.

These results are alarming, but we stress that they are conservative and the actual magnitude of loss and degradation of native vegetation in the study area is certainly greater than that presented here for a number of reasons.

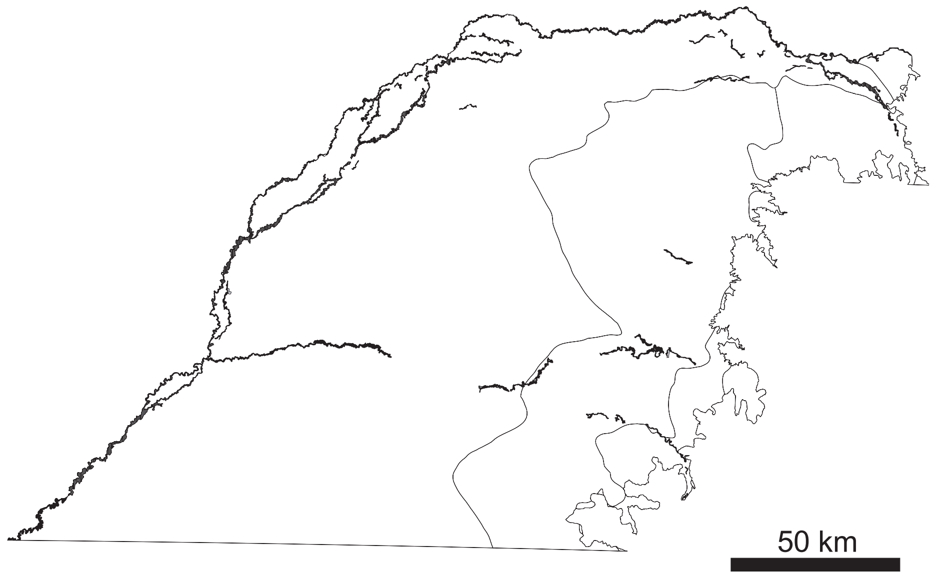

Fig. 18. Vegetation group 3: extensive with low level of clearing (see text). Lines indicate the boundaries of bioregional provinces (Fig. 3).

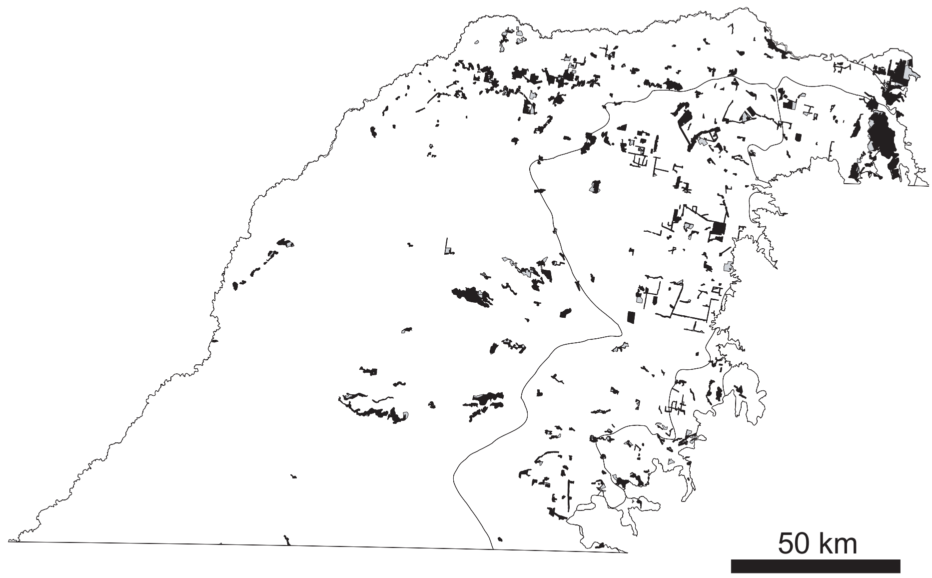

Fig. 19. Vegetation group 4: less common with moderate to heavy level of clearing (see text). Grey areas indicate clearing during the study period. Black areas indicate extant vegetation at the end of the study period. Lines indicate the boundaries of bioregional provinces (Fig. 3).

Firstly, our analysis is restricted to a subset of native vegetation within the study area. The baseline vegetation mapping of Sivertsen and Metcalfe (unpublished) delineates native woody vegetation with average canopy cover of at least 5%. Areas of scattered trees, treeless grasslands, other herbaceous communities and wetlands are not included. Yet all of these will have important conservation values and all are threatened by agricultural modification of the landscape and pressures such as irrigation and changed flooding regimes, inappropriate fire regimes, excessive grazing and weed infestation (Morrison & Bennet 1997, Benson 1999, EPA 2000).

Secondly, the limit of resolution in the baseline vegetation mapping and the Landsat satellite imagery used for this study set a lower limit of 10 ha on the size of remnants included in our analysis. This omits a large number of smaller remnants which, although only accounting for a small percentage of the total extent of native woody vegetation, will have important conservation values in terms of floristic composition, presence of rare plant and animal species, source of propagules and contribution to connectivity within the region. In the most highly depleted areas these small remnants may be the only link to the original native vegetation (Doherty 1998).

Thirdly, we omitted areas marked as uncertain during the interpretation of satellite imagery from the analysis presented here amounting to 17 822 ha for 1998 and 7531 ha for 2000. Our assessment of areas in the uncertain category presented in Table 4 shows that they include additional clearing of native woody vegetation. Ideally, a well-resourced monitoring program would use this category to guide further field or aerial checking.

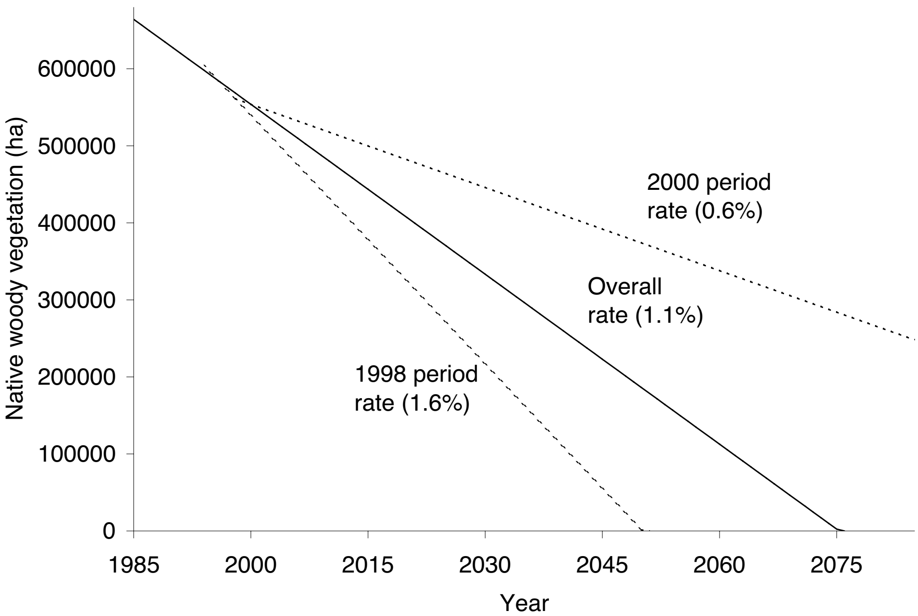

Fig. 20. Simple projection of vegetation losses based on maintaining average annual clearing rates.

Finally, we have reported only the loss of native woody vegetation characterised by the complete removal of the canopy layer or intensive cropping or pasture improvement beneath a sparse tree canopy. This omits thinning of tree cover, removal of very young saplings and degradation of the understorey through excessive grazing, burning or weed infestation, all of which are reportedly widespread in the study area. The effects of irrigation, landforming and changed water flows can also be profound. For example Morrison and Bennett (1997) describe irrigation-induced degradation and loss of Lignum shrublands and Coolabah woodlands in the Gwydir Valley.

Assessment and comparison of mapping methods

Visual interpretation of Landsat TM satellite imagery proved to be a practical and effective method for detecting change due to clearing in the study area including in areas of sparse native woody vegetation. Systematic validation of the technique indicated a high degree of accuracy. Comparison of our mapping with previous mapping largely derived from automated classification methods (ERIC 1998) showed that substantially more clearing was detected. The average annual clearing rate from our mapping was approximately eight times greater than that calculated from the ERIC mapping.

The ERIC study was intended for a broad-scale analysis of statewide clearing patterns. The techniques used allow a relatively rapid assessment of the gross pattern of clearing and trends in relative clearing rates between successive studies. At this level the statewide mapping is valuable but it cannot be used to calculate accurate absolute clearing rates.

Accurate data on vegetation change are essential for landuse planning. The use of methods that seriously underestimate the rate of clearing in sparse vegetation, such as the open woodlands of the study area, risks inappropriate decision making and unforseen negative consequences, both for nature conservation and for sustainable agricultural production. Though it is possible that future advances in digital analysis of satellite data will make automated methods feasible, this does not appear to be the case at present.

Another important limitation of previous studies is that they have only reported gross changes in vegetation cover. In contrast, the methods used in this study, together with baseline maps of extant native vegetation, allow us to report on change in the extent and distribution of individual vegetation types. This is a very considerable advantage for landuse, conservation and vegetation management planning. For statewide reporting of vegetation clearing we would suggest a combined approach that applies the methods used here for regions with adequate vegetation mapping and coarser methods where such mapping is not yet available.

General trends

Figure 8 summarises the general trend in overall clearing rates across monitoring periods. The highest average annual rate, approximately 10 700 ha per year cleared, was recorded for the 1994–1998 monitoring period, possibly in anticipation of the incoming *Native Vegetation Conservation Act*.

The results for the most recent monitoring period, 1998–2000, show a marked overall decline in the average annual clearing rate. However, a thorough validation of these results has yet to be carried out. Ideally, monitoring using similar methods to those used in this study will continue to determine if the rates of clearing remain at or below this lower level. Data on the location and boundaries of approvals granted for clearing, but not yet exercised, would also ideally be integrated into a comprehensive monitoring program. Clearing approvals granted by the NSW Department of Land and Water Conservation are valid for up to four years.

Trends for vegetation types

A number of points stand out from the results for individual vegetation types. Only one relatively common vegetation type, R1: River Red Gum-Coolabah Forests, was not heavily cleared during the study period. All other extensive types suffered substantial reductions from their mapped 1985 extent. Five types had percentage reductions in area that exceeded the general level of native woody vegetation loss.

Regrowth woody vegetation, mapped by Sivertsen and Metcalfe (unpublished) as P9: Open Shrublands and Woodlands was particularly heavily cleared. This could reflect ease of clearing as well as a perception that it is of lower value, in some sense, than other types of vegetation. Sivertsen and Metcalfe (unpublished) noted that many stands of this vegetation type showed obvious signs of disturbance and modification. Rapid clearing of Open Shrublands and Woodlands in the 1994–1998 monitoring period contributed to the high average annual clearing rate for overall vegetation. The *Native Vegetation Conservation Act* presently allows for clearing of regrowth vegetation that is up to ten years old. However, the stands of Shrublands and Woodlands mapped by Sivertsen and Metcalfe that remain will all now be older than this. Doherty (1998) points out that remnants of native vegetation that are secondary or even tertiary regrowth still represent a link to the original vegetation of a region and are of conservation value.

Coolabah (*Eucalyptus coolabah*) dominated woodlands were particularly heavily cleared during the study period. Large stands of Coolabah had been cleared prior to this study and others were apparently killed by altered flooding regimes in the Gwydir River valley (Morrison & Bennett 1997). The present rates of decline are thus of serious concern and, if maintained, would be expected to lead to population decline in a wide range of species.

Cumulative loss of vegetation

As the total area of native vegetation is reduced, the cumulative impact of each successive clearing event becomes greater. We found that an average of 7355 ha, or 1.1% of the total area of native woody vegetation mapped for 1985, was cleared during each year of the study period (Table 5). If this average rate was maintained then the actual percentage of vegetation lost in any given year would steadily increase (Fig. 21 lower curve). The upper curve (Fig. 21) shows what would result if the average annual clearing rate for the 1994–1998 period was maintained. These curves emphasise the need for frequent monitoring of vegetation clearing since apparently modest long term averages can mask high short-term losses.

The analysis of the proportion of native woody vegetation cleared within 10 km radius neighbourhoods across the study area illustrates another aspect of cumulative loss (Fig. 11). Areas to the east of Collarenebri and Mungindi are highlighted because of very large clearing events in these vicinities. But other areas, such as those to the north-east and north-west of Moree where the extent of clearing was much smaller, are also highlighted. In these areas there was very little native woody vegetation remaining by 1985 and so any clearing represents a large proportional loss.

Attempts to predict and mitigate the effects of vegetation clearing

Theoretical and empirical studies suggest that there can be a substantial time lag between habitat loss or modification and the onset of population declines and extinctions, an effect referred to as extinction debt (Saunders et al. 1991, Tilman et al. 1994). This implies that in an extensively cleared region predicting the implications of further habitat loss, or setting thresholds for maximum acceptable modification of the landscape, becomes increasingly precarious.

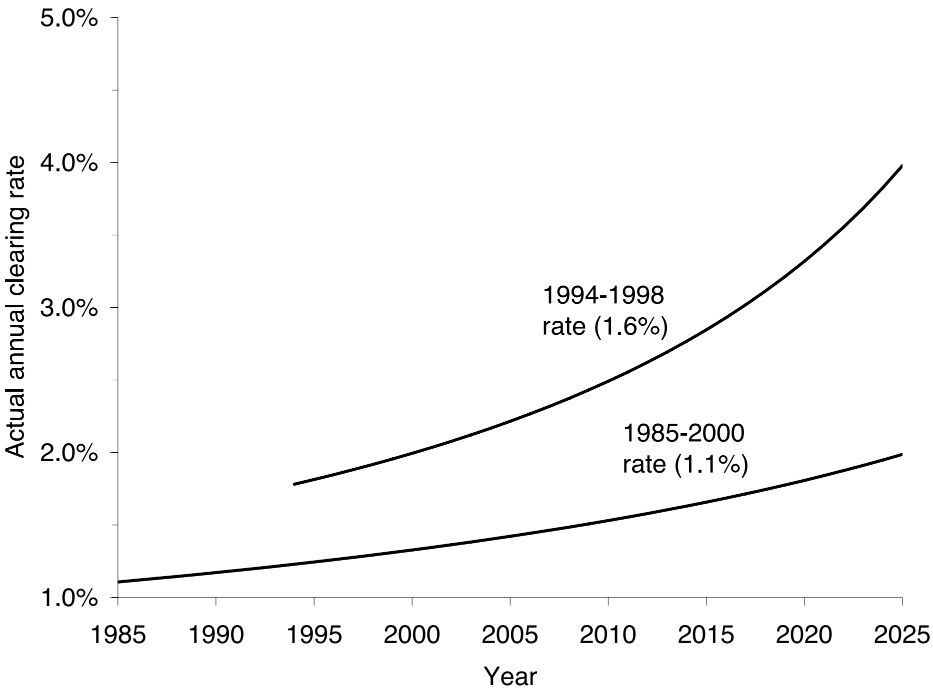

Fig. 21. Increase in the actual annual clearing rate over a 40 year period. The lower curve is based on the overall average clearing rate for 1985–2000. The upper curve is for the average rate for the monitoring period 1994–1998.

Other studies suggest that the relationship between habitat reduction and species loss in a region is likely to be highly non-linear and that there may be critical levels of habitat reduction beyond which the loss of species greatly accelerates (Andren 1994, Green 1994). One mechanism is the sudden decrease in spatial connectivity between vegetation remnants when the total vegetation cover is reduced below a certain point. Our ignorance on these issues is profound. It is difficult to say which groups of species will display population behaviour of the type seen in theoretical models or what the critical thresholds might be for different groups.

Various schemes for setting landuse limits within agricultural landscapes have been put forward (e.g. Freudenberger et al. 1997, McIntyre 2000, Reid 2000) that attempt to either prevent native vegetation cover falling below some critical point or, where it is already highly depleted, to restore the level of native vegetation to some level. Current vegetation management proposals include:

- setting targets for the retention or restoration of native vegetation cover;
- setting limits on the extent of overall vegetation or individual vegetation types that can be cleared;
- setting limits on the proportion of vegetation types that can be converted to intensive land uses such as cropping;
- increasing the area devoted to conservation through reserves, Voluntary Conservation Agreements or other mechanisms.

There is little science on which to base the setting of any such targets and limits, but values between 30–40% for retention of native woody vegetation cover have been widely advocated.

The mapping of Sivertsen and Metcalfe (unpublished) shows that the total cover of native woody vegetation in the study area had been reduced to 27.3% by 1985. Despite this, vegetation clearance has continued and at the end of our study period the figure had fallen to 22.8%. Levels of remaining cover vary between the three major bioregional provinces. In the Northern Outwash province total cover had fallen to 7.1% (Table 6). In terms of individual vegetation types precise pre-clearing areas are not available but many types, such as Brigalow Woodlands, have been reduced to a very small percentage of their former extent while others, such as the Coolabah dominated woodlands, have been subjected to recent extensive clearing. Any further clearing will narrow what options still remain to conserve a minimal level of native woody vegetation cover and attempt to expand remnants in the most depleted areas.

Implications for the *Native Vegetation Conservation Act* and regional vegetation management

With the implementation of the *NSW Native Vegetation Conservation Act* at the beginning of 1998, the management of native vegetation shifted to a regional model. The intention was to provide a framework for communication and cooperation between landholders, state and local government representatives, conservation groups, aboriginal representatives and scientists through Regional Vegetation Committees. Potentially, this could lead to an integrated consideration of sustainable agricultural production and conservation, but its success depends, in large measure, on our ability to provide the necessary high quality information required for decision making.

For native woody vegetation this information includes accurate vegetation mapping and monitoring of change. Comparison of the results of this study with data presented by ERIC (1998) shows that previous mapping of the location and extent of native woody vegetation clearance has seriously underestimated clearing rates. This is a result of the inability of automated classification methods to detect change in sparse woody vegetation that characterises much of the study area. As such, we conclude that this mapping is not a suitable basis for regional vegetation management.

A stated intention of the *Native Vegetation Conservation Act* is to prevent inappropriate clearing. Given very low total cover of native woody vegetation in the Northern Outwash bioregional province at the start of the study period, it could be assumed that any further clearing within the province would have been inappropriate. Instead, our analysis has shown that a high proportion of the remaining native woody vegetation was cleared in areas within the province (Fig. 11) and the average annual clearing rate steadily increased over the study period (Fig. 12). Thus far, the *Native Vegetation Conservation Act*, as well as *State Environmental Planning Policy No. 46* that preceded it, appear to have failed to prevent further decline in this very extensively cleared province.

Fragmentation effects

Our results show that for overall native woody vegetation, and most vegetation types, fragmentation has increased. Vegetation remnants, and patches of vegetation types, have become generally smaller as large remnants were reduced in size or separated into disjunct parts. The vulnerability to edge effects, as measured by exposed perimeter to area ratio, increased for almost all vegetation types. There are very few stands of any mapped vegetation type that are not adjacent to cleared land.

A comprehensive analysis of the effects of fragmentation on the biodiversity of the study area is beyond the scope of this study. The effects of the loss of vegetation cover through clearing, the spatial arrangement of vegetation remnants, condition and disturbance attributes, and the requirements and distribution of particular plant and animal taxa are all important and will interact in complex ways. There is a great need for further research. However, we agree with Reid (2000) that in the case of habitat loss on the massive scales seen in the New South Wales wheatbelt, attempting to separate the influence of habitat reduction from that of fragmentation on species extinctions is futile and irrelevant. Instead, there is a clear imperative to halt the present decline in native woody vegetation cover and enhance the size and quality of existing remnants.

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Apppendix: Detailed results for vegetation types.

The names and descriptions of vegetation types are taken from the unpublished data and mapping of Sivertsen and Metcalfe. Descriptions of vegetation structure follow the terminology of Walker and Hopkins (1984). Bioregional provinces referred to in the descriptions are those of Morgan and Terrey (1992) and are shown in Fig. 3.

Type R1: River Red Gum-Coolabah Forests

Description

This vegetation type is found along river banks, channels and back plains of the floodplain. Common canopy species are *Eucalyptus camaldulensis* and *Eucalyptus coolabah*. Typically it is restricted to narrow bands in close proximity to rivers on alluvial clays and grey cracking clays. It is found in all bioregional provinces within the study area.

Clearing within 20 metres of a watercourse has been prohibited since 1938 under the *Soil Conservation Act* and continues to be prohibited under the *Native Vegetation Conservation Act.*

Clearing

There was a relatively small amount of clearing in River Red Gum-Coolabah Forests over the study period, amounting to just over 1% of the area mapped in 1985 (Table 8).

Fragmentation

All mapped patches of River Red Gum-Coolabah Forests were adjacent to cleared areas. The number of patches and the range of patch sizes remained stable over the study period (Table 8, Fig. 22) though the median size decreased in the period ending 1998.

Table 8. Results for R1: River Red Gum-Coolabah Forests.

	1985	**1994**	**1998**	**2000**	**Overall**
Remaining extent (ha)	39 415	39 298	39 076	38 960	
Area cleared (ha)	-	117	222	116	**455**
Area cleared (% 1985 vegetation)	-	0.3%	0.6%	0.3%	**1.2%**
Average annual clearing rate (ha/yr)	-	13	56	58	**30**
Average annual clearing rate (as % 1985 vegetation)	-	0.03%	0.14%	0.15%	**0.08%**
Average annual clearing rate (as % previous area)	-	0.03%	0.14%	0.15%	
Number of patches	54	52	54	54	
Median patch area (ha) (min–max)	190 (18–11 877)	189 (18–11 879)	170 (18–11 875)	170 (18–11 875)	
Number of patches adjacent to clearing	54	52	54	54	
Median P/A ratio (m/ha) for patches adjacent to clearing	61.76	63.63	63.63	58.52	

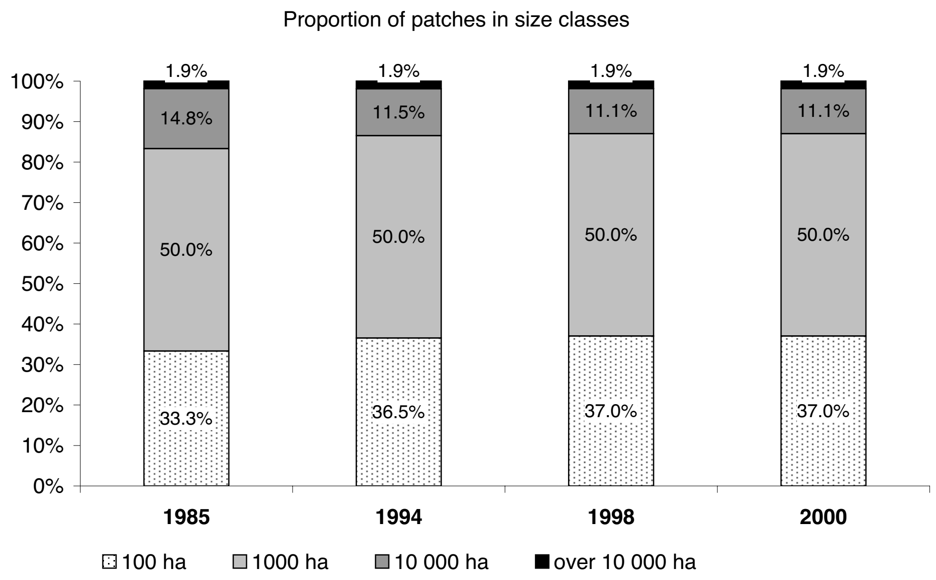

Fig. 22. The proportion of patches of R1: River Red Gum-Coolabah Forests in each of four size classes.

Type R2: Floodplain Mosaic

Description

This is a complex vegetation type with structure varying from tall open forests to low woodlands, sedgelands and grasslands. It is associated with grey cracking clays of floodplains and backplains. Common canopy species include *Eucalyptus coolabah*, *Eucalyptus largiflorens* and *Casuarina cristata*, with some *Eucalyptus camaldulensis* and *Eucalyptus populnea* subsp. *bimbil*. It is concentrated in two areas, the first in the northern-most part of the study area along the Macintyre, Boomi and Whalan Rivers, with a small patch on the Barwon River. The other occurrence is between Collarenebri, Moree and the southern boundary of the study area. Both areas are mostly within the Castlereagh-Barwon province.

Clearing

Floodplain Mosaic was heavily cleared during the study period, with a total loss of 13 900 ha amounting to 19% of the extent mapped for 1985 (Table 9). The overall average clearing rate, as a percentage of 1985 extent, was higher than the general rate of vegetation loss in the study area (cf. Table 7).

In the period ending 1994, there were a series of small to medium clearing events in the northern part of the study area. The following period, ending 1998, saw a doubling of the average clearing rate to about 1500 ha per year. There were large clearing events in the southern part of the study area near the confluence of the Gwydir and Barwon rivers. A particularly large series of clearing episodes occurred near Rowena on Thalaba Creek. The final 1998–2000 period saw a substantial reduction in the clearing rate.

Fragmentation

Compared to the beginning of the study period, stands of Floodplain Mosaic have become smaller and more prone to edge effects (Table 9, Fig. 23). There has been a steady increase in the proportion of patches of 1000 ha or less at the expense of the larger size classes. Median patch size decreased by 40% over the study period. The steady increase in patch perimeter to area ratio indicates increasing vulnerability to edge effects as previously large contiguous stands are reduced and sometimes subdivided by clearing.

Table 9. Results for R2: Floodplain Mosaic

	1985	1994	1998	2000	Overall
Remaining extent (ha)	71 586	64 674	58 514	57 639	
Area cleared (ha)	-	6912	6161	875	**13 948**
Area cleared (% 1985 vegetation)	-	9.7%	8.6%	1.2%	**19.5%**
Average annual clearing rate (ha/yr)	-	768	1540	437	**930**
Average annual clearing rate (as % 1985 vegetation)	-	1.07%	2.15%	0.61%	**1.30%**
Average annual clearing rate (as % previous area)	-	1.07%	2.38%	0.75%	
Number of patches	75	97	112	116	
Median patch area (ha) (min–max)	348 (9–11 494)	208 (1–10 200)	131 (1–9700)	117 (1–9700)	
Number of patches adjacent to clearing	74	96	111	115	
Median P/A ratio (m/ha) for patches adjacent to clearing	28.90	33.41	38.51	44.80	

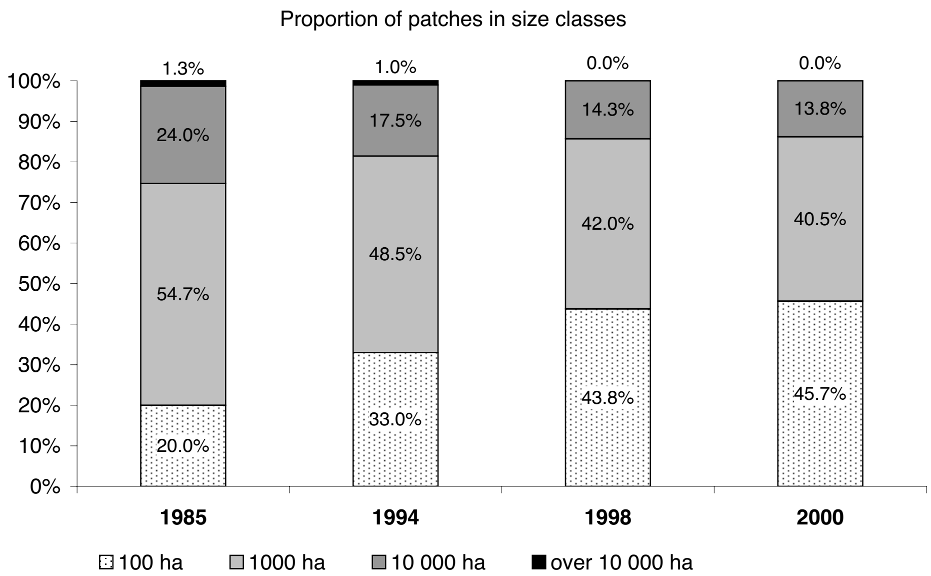

Fig. 23. The proportion of patches of R2: Floodplain Mosaic in each of four size classes.

Type R3: Coolabah Woodlands

Description

This vegetation type varies in structure from tall open forests through to open woodlands. The canopy is dominated by *Eucalyptus coolabah, Eucalyptus camaldulensis* and *Casuarina cristata*. It is usually associated with grey cracking clays on floodplains and closed depressions. Most occurrences are in the south west corner of the study area, along the Barwon River, Pian Creek, Thalaba Creek, Moomin, Mehi, and Gwydir Rivers, and Gingham watercourse. Further north, they occur on Croppa Creek, the Macintyre and Barwon Rivers. Most of the distribution is in the Castlereagh-Barwon province with some minor occurrences further east.

Clearing

Over 12 000 ha of Coolabah Woodlands, 14.5% of the mapped 1985 extent, were cleared during the study period (Table 10). The overall percentage rate of loss was slightly below the general rate of vegetation loss in the study area (cf. Table 7). The highest average annual clearing rate, over 1000 ha per year, was recorded for the period ending 1998. The rate decreased to about a quarter of this level in the period ending 2000.

Fragmentation

There was an increase in the number of patches over the study period while minimum, maximum and median patch sizes all decreased. The number of patches up to 100 ha in area steadily increased at the expense of the larger size classes (Table 10, Fig. 24). Almost all patches of Coolabah Woodlands are adjacent to clearing and there was an increased vulnerability to edge effects as indicated by increasing patch perimeter to area ratios.

Table 10. Results for R3: Coolabah Woodlands

	1985	**1994**	**1998**	**2000**	**Overall**
Remaining extent (ha)	86 064	78 408	74 120	73 550	
Area cleared (ha)	-	7656	4288	570	**12 514**
Area cleared (% 1985 vegetation)	-	8.9%	5.0%	0.7%	**14.5%**
Average annual clearing rate (ha/yr)	-	851	1072	285	**834**
Average annual clearing rate (as % 1985 vegetation)	-	0.99%	1.25%	0.33%	**0.97%**
Average annual clearing rate (as % previous area)	-	0.99%	1.37%	0.38%	
Number of patches	98	109	123	126	
Median patch area (ha) (min–max)	182 (13–21 811)	154 (1–17 884)	137 (1–17 507)	135 (1–17 406)	
Number of patches adjacent to clearing	95	106	120	124	
Median P/A ratio (m/ha) for patches adjacent to clearing	32.32	35.31	42.56	42.97	

Type R4: Lignum Shrublands

Description

Lignum Shrublands are dominated by *Muehlenbeckia florulenta* and *Acacia stenophylla*. In the wheatbelt they are found on the grey cracking clays of banks, flats and swamps of the alluvial floodplains. In the present study area this vegetation type is restricted to four isolated stands along watercourses. However, it may be more extensive since it is difficult to identify from aerial photography.

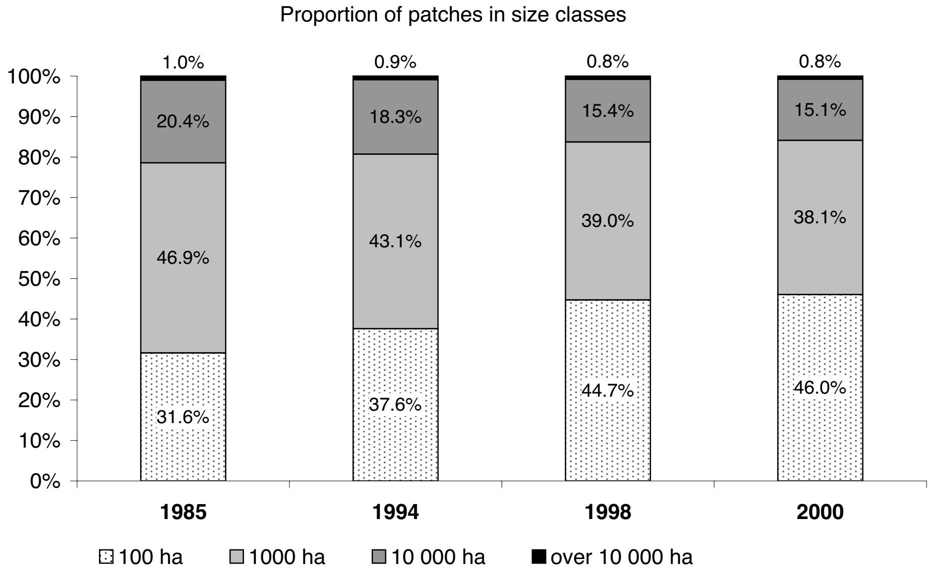

Fig. 24. The proportions of patches of R3: Coolabah Woodlands in each of four size classes.

Clearing

Of the 1212 ha of Lignum Shrublands mapped for 1985, 357 ha were cleared over the study period, a 29% reduction in the mapped 1985 extent (Table 11).

Fragmentation

Partial clearing of two of the original four patches is reflected in the increase in perimeter to area ratio. The distribution of patch sizes is not graphed for this small number of patches. All but one of the patches are adjacent to clearing.

Type R5: Myall Woodlands

Description

Myall Woodlands vary from mid-high to low open woodland. The canopy is dominated by *Acacia pendula*, with *Geijera parviflora, Alectryon oleifolius* and *Acacia farnesiana* present as occasional components. It is associated with gilgaied brown & grey cracking clays. Within the present study area it is mostly found in the Northern Outwash and Northern Basalts provinces.

This community is often difficult to distinguish on aerial photography and hence could have been more extensive than originally mapped in 1985.

Clearing

Nearly 10% of the mapped 1985 extent of Myall Woodlands was cleared during the study period (Table 12). The highest clearing rate was recorded for the period ending 1998 with much lower rates in the both the preceding and subsequent periods.

Fragmentation

There was a 30% decrease in the median size of patches over the study period. All patches are adjacent to cleared land and their vulnerability to edge effects, as measured by perimeter to area ratio, increased. The proportion of patches of up to 100 ha increased at the expense of the largest size class (Fig. 25).

Table 11. Results for R4: Lignum Shrublands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	1212	1207	1047	855	
Area cleared (ha)	-	5	159	192	**357**
Area cleared (% 1985 vegetation)	-	0.5%	13.1%	15.9%	**29.5%**
Average annual clearing rate (ha/yr)	-	1	40	96	**24**
Average annual clearing rate (as % 1985 vegetation)	-	0.05%	3.29%	7.94%	**1.96%**
Average annual clearing rate (as % previous area)	-	0.05%	3.30%	9.19%	
Number of patches	4	4	4	5	
Median patch area (ha) (min–max)	249 (129–586)	247 (129–585)	247 (129–426)	129 (42–426)	
Number of patches adjacent to clearing	3	3	3	4	
Median P/A ratio (m/ha) for patches adjacent to clearing	41.19	42.88	44.28	64.94	

Table 12. Results for R5: Myall Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	8466	8346	7675	7627	
Area cleared (ha)	-	120	671	48	**839**
Area cleared (% 1985 vegetation)	-	1.4%	7.9%	0.6%	**9.9%**
Average annual clearing rate (ha/yr)	-	13	168	24	**56**
Average annual clearing rate (as % 1985 vegetation)	-	0.16%	1.98%	0.28%	**0.66%**
Average annual clearing rate (as % previous area)	-	0.16%	2.01%	0.31%	
Number of patches	18	18	23	23	
Median patch area (ha) (min–max)	190 (11–2040)	190 (11–2038)	103 (1–1648)	103 (1–1623)	
Number of patches adjacent to clearing	18	18	23	23	
Median P/A ratio (m/ha) for patches adjacent to clearing	34.33	34.22	43.28	44.14	

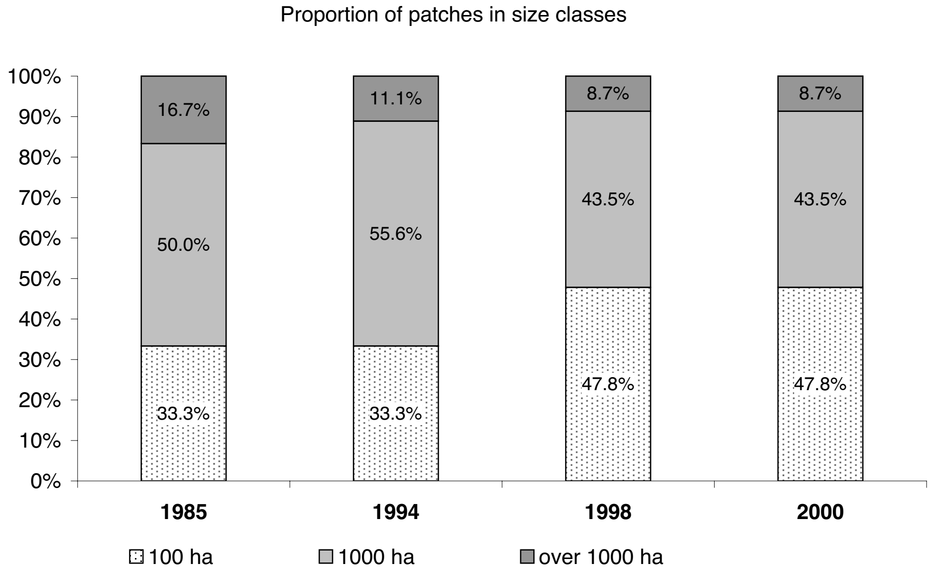

Fig. 25. The proportions of patches of R5: Myall Woodland in each of three size classes.

Type R7: Coolabah-Poplar Box Woodlands

Description

This vegetation type ranges in structure from woodlands to tall open woodlands with some grassland inclusions. Characteristic canopy species are *Eucalyptus populnea* subsp. *bimbil*, *Eucalyptus coolabah*, and *Casuarina cristata*. It occurs on the interzone between the black soil dominated alluvial plain and the more elevated earthy soil of the peneplain. This interzone comprises elements of both soil types in a complex mosaic. Within the mosaic, areas of treeless grassland occur in sinuous bands which follow relict, in-filled watercourses. Most occurrences are in the Castlereagh-Barwon province with some relatively isolated remnants in the Northern Outwash province north of Moree.

Clearing

11679 ha of Coolabah-Poplar Box Woodlands, 12.4% of the mapped 1985 extent, were cleared over the study period (Table 13). The highest clearing rate was in the period ending 1998. Clearing during this period mainly occurred close to watercourses, with clearing events between Moomin and Mehi watercourses, along the Gingham watercourse, and along the Barwon, Boomi & Macintyre Rivers. The clearing rate in the subsequent period decreased by more than 50%.

Fragmentation

Over the study period, patches of Coolabah-Poplar Box Woodlands have become smaller, more numerous and more prone to edge effects (Table 13, Fig. 26). The median size of patches decreased by 30% and the number of patches in the up to 100 ha category increased by nearly three times at the expense of the larger size classes. Almost all patches are adjacent to cleared land and became generally more vulnerable to edge effects as measured by perimeter to area ratio.

Table 13. Results for R7: Coolabah-Poplar Box Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	93 935	87 050	83 103	82 256	
Area cleared (ha)	-	6885	3947	847	**11 679**
Area cleared (% 1985 vegetation)	-	7.3%	4.2%	0.9%	**12.4%**
Average annual clearing rate (ha/yr)	-	765	987	424	**779**
Average annual clearing rate (as % 1985 vegetation)	-	0.81%	1.05%	0.45%	**0.83%**
Average annual clearing rate (as % previous area)	-	0.81%	1.13%	0.51%	
Number of patches	116	150	166	170	
Median patch area (ha) (min–max)	334 (41–9212)	194 (1–8802)	184 (1–7766)	174 (1–7658)	
Number of patches adjacent to clearing	114	148	164	169	
Median P/A ratio (m/ha) for patches adjacent to clearing	32.89	44.11	47.53	47.53	

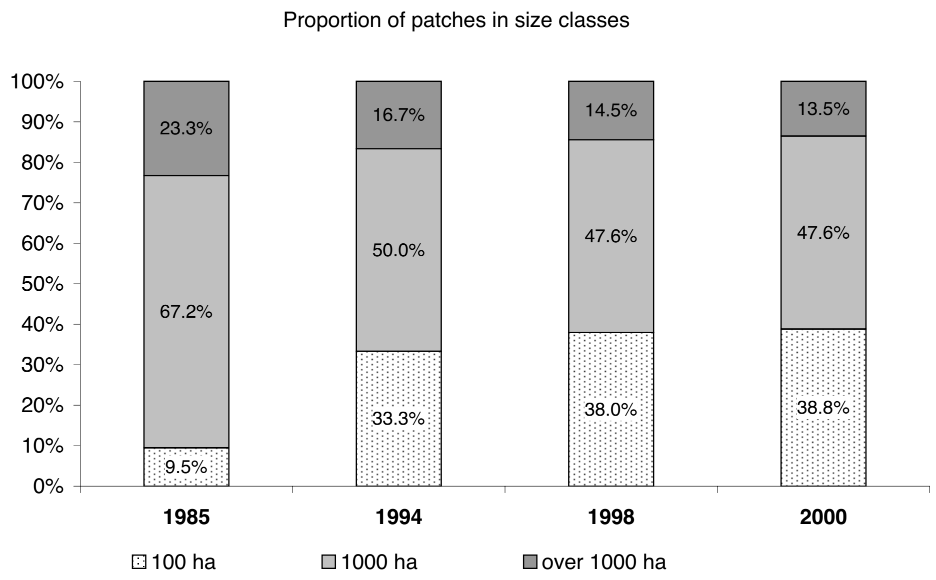

Fig. 26. The proportion of patches of R7: Coolabah-Poplar Box Woodlands in each of three size classes.

Type R8: White Cypress Pine-Carbeen Woodlands

Description

This vegetation type varies from tall open forests to tall open woodlands. A number of temperate dry rainforest taxa are found in the canopy and understorey. Characteristic canopy species include *Callitris glaucophylla, Corymbia tessellaris, Eucalyptus populnea* subsp. *bimbil, Corymbia dolichocarpa*, *Eucalyptus camaldulensis, Casuarina cristata and Allocasuarina luehmannii.* It occurs on siliceous sands and minor earthy sands on flats and gentle rises of the alluvial plain and is concentrated in the northern part of the Castlereagh-Barwon province north of Whalan creek.

This type corresponds to Carbeen Open Forest which was listed as a Endangered Ecological Community under the New South Wales Threatened Species Conservation Act in 1999.

Clearing

1970 ha of White Cypress Pine-Carbeen woodlands, 11.9% of the mapped 1985 extent, were cleared over the study period (Table 14). The highest clearing rate was in the period ending 1998. Most clearing took place in the northern part of the study area as well as on the Gwydir raft near Moree, where this type is present as scattered stands. About 250 ha were cleared between Mungindi and Collarenebri in a narrow band of remnants parallel to the Barwon River. The clearing rate decrease substantially in the final period ending 2000.

Fragmentation

Median patch area fell substantially over the study period, especially in the period ending 1998 (Table 14). The distribution of patch sizes was more stable than for some other vegetation types though there was an increase in the proportion of patches in the smallest (up to 100 ha) size class (Fig. 27). Nearly all patches are adjacent to cleared areas and their vulnerability to edge effects, as measured by perimeter to area ratio, increased.

Table 14. Results for R8: White Cypress Pine-Carbeen Woodlands

	1985	**1994**	**1998**	**2000**	**Overall**
Remaining extent (ha)	16 521	15 660	14 644	14 551	
Area cleared (ha)	-	861	1016	93	**1970**
Area cleared (% 1985 vegetation)	-	5.2%	6.1%	0.6%	**11.9%**
Average annual clearing rate (ha/yr)	-	96	254	47	**131**
Average annual clearing rate (as % 1985 vegetation)	-	0.58%	1.54%	0.28%	**0.80%**
Average annual clearing rate (as % previous area)	-	0.58%	1.62%	0.32%	
Number of patches	58	63	67	67	
Median patch area (ha) (min–max)	172 (12–1518)	136 (1–1517)	100 (1–1517)	100 (1–1424)	
Number of patches adjacent to clearing	55	60	64	64	
Median P/A ratio (m/ha) for patches adjacent to clearing	44.38	49.56	54.64	54.64	

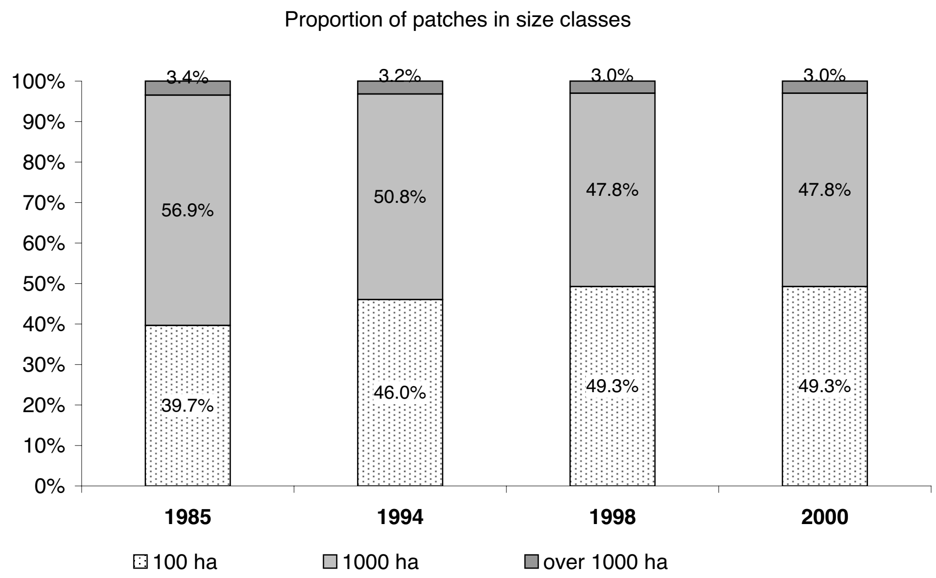

Fig. 27. The proportion of patches of R8: White Cypress Pine-Carbeen Woodlands in each of three size classes.

Type R10: Open Coolabah Woodlands

Description

This vegetation type varies from mid-high to tall woodlands and open woodlands. *Eucalyptus coolabah* dominates the canopy with *Casuarina cristata* and *Acacia stenophylla* also present. It occurs on the grey cracking clays of the banks and floodplains of Gill Gill Creek, the Gwydir River and Pian Creek in the Castlereagh-Barwon province.

Clearing

Open Coolabah Woodlands were one of the most heavily cleared vegetation types. The overall clearing rate of 1.25% of 1985 extent per year is greater than the overall rate of vegetation loss in the study area (cf. Table 7). 16 314 ha, more than 18% of the mapped 1985 extent, was cleared during the study period (Table 15). The highest clearing rate was in the period ending 1998. Most clearing occurred in the vicinities of Rowena and Collarenebri as well as along the Mehi River, about 50 km west of Moree. The clearing rate fell substantially in the final period ending 2000.

Fragmentation

Open Coolabah Woodlands became substantially more fragmented as measured by all summary statistics (Table 15). Minimum and maximum patch sizes decreased and there was a very marked decrease in median size from 1265 ha to 81 ha. This is also indicated by the changing distribution of patch sizes (Fig. 28) with the proportion of patches in the smallest size class, up to 100 ha, increasing by more than 8 times over the study period at the expense of the large size classes. All patches are adjacent to clearing and their overall vulnerability to edge effects, as measured by perimeter to area ratio, increased markedly.

Table 15. Results for R10: Open Coolabah Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	86 689	77 409	71 449	70 375	
Area cleared (ha)	-	9280	5961	1073	**16 314**
Area cleared (% 1985 vegetation)	-	10.7%	6.9%	1.2%	**18.8%**
Average annual clearing rate (ha/yr)	-	1031	1490	537	**1088**
Average annual clearing rate (as % 1985 vegetation)	-	1.19%	1.72%	0.62%	**1.25%**
Average annual clearing rate (as % previous area)	-	1.19%	1.93%	0.75%	
Number of patches	23	44	57	64	
Median patch area (ha) (min–max)	1265 (72–17 772)	227 (1–15 203)	101 (1–13 249)	81 (1–13 245)	
Number of patches adjacent to clearing	23	44	57	64	
Median P/A ratio (m/ha) for patches adjacent to clearing	17.32	39.08	51.73	59.18	

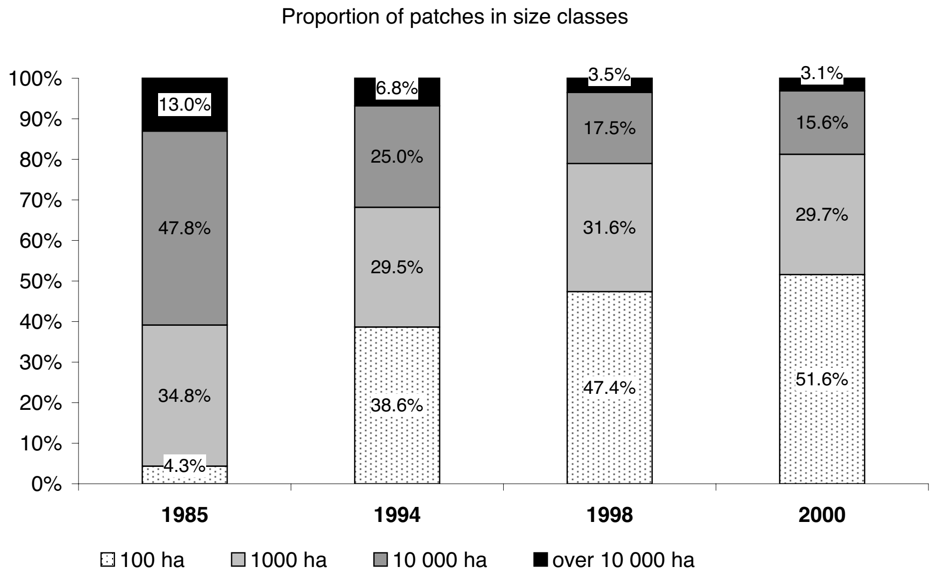

Fig. 28. The proportion of patches of R10: Open Coolabah Woodlands in each of four size classes.

Type P3: Open Poplar Box Woodlands

Description

This vegetation type varies in structure from mid-high to tall open woodlands. *Eucalyptus populnea* subsp. *bimbil* is the most common canopy species with *Casuarina cristata, Acacia harpophylla* and *Eucalyptus melanophloia* also present. It is mostly found on loamy red earths of flats, gentle slopes and low crests. The distribution takes in the eastern two thirds of the study area with occurrences in the Castlereagh-Barwon, Northern Outwash and Northern Basalts provinces.

Clearing

Open Poplar Box Woodlands were among the most heavily cleared vegetation types. The overall clearing rate of 1.24% of 1985 extent was higher than the overall rate of vegetation loss in the study area (cf. Table 7). 4085 ha, or 18.6% of the mapped 1985 extent, were cleared over the study period (Table 16). The highest clearing rate was in the period ending 1998. The subsequent period saw the rate drop by about two thirds.

Fragmentation

Median patch size decreased by about 25% (Table 16). All patches are adjacent to clearing and their vulnerability to edge effects, as measured by perimeter to area ratio, increased. The proportion of patches in size classes remained relatively stable over the study period (Fig. 29).

Table 16. Results for P3: Open Poplar Box Woodlands

	1985	**1994**	**1998**	**2000**	**Overall**
Remaining extent (ha)	21 954	19 587	18 083	17 869	
Area cleared (ha)	-	2367	1504	214	**4085**
Area cleared (% 1985 vegetation)	-	10.8%	6.9%	1.0%	**18.6%**
Average annual clearing rate (ha/yr)	-	263	376	107	**272**
Average annual clearing rate (as % 1985 vegetation)	-	1.20%	1.71%	0.49%	**1.24%**
Average annual clearing rate (as % previous area)	-	1.20%	1.92%	0.59%	
Number of patches	79	82	88	89	
Median patch area (ha) (min–max)	175 (12–1607)	145 (12–1607)	124 (2–1470)	117 (2–1470)	
Number of patches adjacent to clearing	79	82	88	89	
Median P/A ratio (m/ha) for patches adjacent to clearing	46.55	52.63	60.44	60.88	

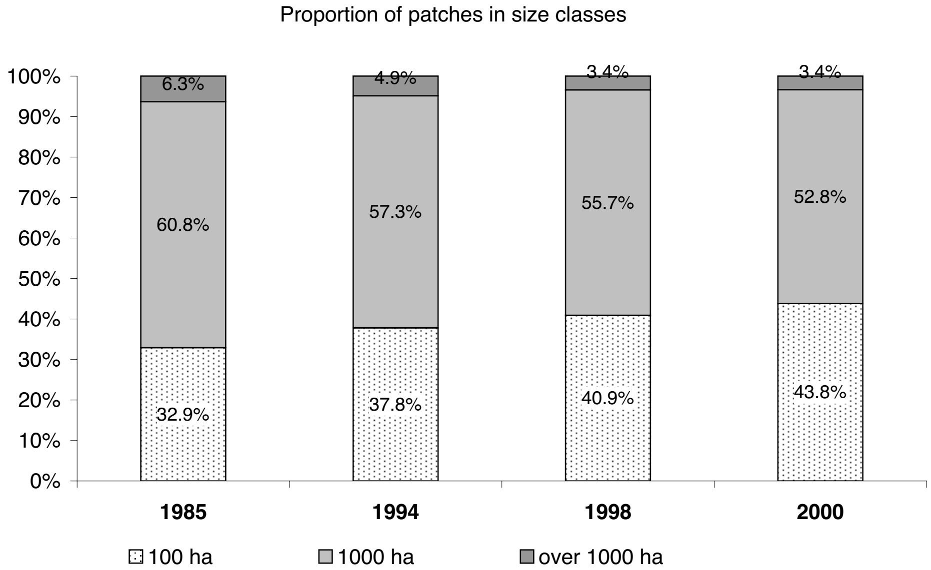

Fig. 29. The proportion of patches of P3: Open Poplar Box Woodlands in each of three size classes.

Type P4: Poplar Box Woodlands

Description

This vegetation type is very similar in composition to P3: Open Poplar Box Woodlands and is distinguished by its more continuous canopy cover. Common canopy species include *Eucalyptus populnea* subsp. *bimbil*, *Eucalyptus melanophloia, Casuarina cristata* and *Callitris glaucophylla*. Both habitat and distribution are similar to P3: Open Poplar Box Woodlands.

Clearing

This was one of the less cleared vegetation types with 1097 ha, or 9.8% of the mapped 1985 extent, being cleared during the study period (Table 17). The highest clearing rate was recorded in the period ending 2000.

Fragmentation

Median patch size decreased by about 25% over the study period. Almost all patches are adjacent to clearing and their vulnerability to edge effects, as measured by exposed perimeter to area ratio, increased (Table 17). The proportion of remnants across size classes remained relatively stable over the study period (Fig. 30).

Table 17. Results for P4: Poplar Box Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	11 205	10 586	10 449	10 107	
Area cleared (ha)	-	618	137	342	**1097**
Area cleared (% 1985 vegetation)	-	5.5%	1.2%	3.0%	**9.8%**
Average annual clearing rate (ha/yr)	-	69	34	171	**73**
Average annual clearing rate (as % 1985 vegetation)	-	0.61%	0.31%	1.52%	**0.65%**
Average annual clearing rate (as % previous area)	-	0.61%	0.32%	1.64%	
Number of patches	58	60	59	61	
Median patch area (ha) (min–max)	94 (17–2369)	69 (17–2275)	67 (17–2275)	67 (12–2275)	
Number of patches adjacent to clearing	57	59	58	60	
Median P/A ratio (m/ha) for patches adjacent to clearing	59.63	63.69	67.62	67.62	

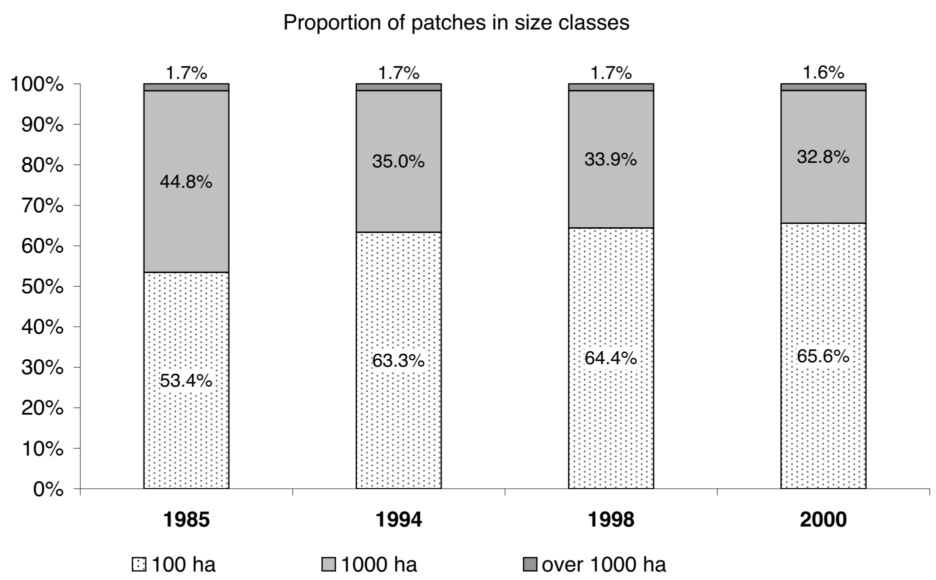

Fig. 30. The proportion of patches of P4: Poplar Box Woodlands in each of three size classes.

Type P6: Iron Bark-White Cypress Pine Woodlands

Description

This vegetation type forms a mid-high open forest with *Eucalyptus melanophloia*, *Callitris glaucophylla* and *Eucalyptus populnea* subsp. *bimbil* as the dominant canopy species. It is found on red earths on flats. Within the study area two small remnants were mapped by Sivertsen and Metcalfe (unpublished), one in the Northern Outwash province and the other in the Northern Basalt province.

Clearing

No clearing was recorded in the 132 ha of Iron Bark-White Cypress Pine Woodlands mapped in the study area (Table 18).

Table 18. Results for P6: Iron Bark-White Cypress Pine Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	132	132	132	132	
Area cleared (ha)	-	0	0	0	**0**
Area cleared (% 1985 vegetation)	-	-	-	-	**-**
Average annual clearing rate (ha/yr)	-	-	-	-	**-**
Average annual clearing rate (as % 1985 vegetation)	-	-	-	-	**-**
Average annual clearing rate (as % previous area)	-	-	-	-	
Number of patches	2	-	-	-	
Median patch area (ha) (min–max)	66 (27–105)	- -	- -	- -	
Number of patches adjacent to clearing	2	-	-	-	
Median P/A ratio (m/ha) for patches adjacent to clearing	60.85	-	-	-	

Type P8: Belah Woodlands

Description

This vegetation type varies in structure from mid-high to tall woodlands through to open woodlands. *Casuarina cristata* is the dominant canopy species with *Acacia harpophylla, Eucalyptus populnea* subsp. *bimbil*, and *Eucalyptus microcarpa* also present. It occurs on brown and grey clays of flats, very gentle slopes and minor streamlines. Within the present study area much of the distribution is in the Northern Outwash province as roadside remnants, windbreaks and riparian verges. Some larger remnants exist in the north of the study area in the Castlereagh Barwon province. There are also a small number of occurrences in the Northern Basalts province.

Clearing

The rate of loss for Belah Woodlands was about equal to the overall rate of vegetation loss for the study period. 1988 ha, or 16.3% of the mapped 1985 extent, were cleared (Table 19). The rate of clearing remained stable for the periods ending 1994 and 1998 with small clearing events scattered quite evenly throughout the distribution. Some patches were completely removed but most clearing appeared to be 'tidying up' of small areas leaving linear remnants. The final period saw the clearing rate drop by about 60%.

Fragmentation

At the start of the study period Belah Woodlands were already highly vulnerable to edge effects. There were no patches greater than 1000 ha and 59% were less than 100 ha. During the study period the median patch area decreased by about 20% (Table 19) and the proportion of patches in the smallest size class increased (Fig. 31). All patches are adjacent to clearing and their vulnerability to edge effects, as measured by perimeter to area ratio, increased.

Table 19. Results for P8: Belah Woodlands

	1985	**1994**	**1998**	**2000**	**Overall**
Remaining extent (ha)	12 172	10 897	10 291	10 184	
Area cleared (ha)	-	1275	606	107	**1988**
Area cleared (% 1985 vegetation)	-	10.5%	5.0%	0.9%	**16.3%**
Average annual clearing rate (ha/yr)	-	142	152	54	**133**
Average annual clearing rate (as % 1985 vegetation)	-	1.16%	1.24%	0.44%	**1.09%**
Average annual clearing rate (as % previous area)	-	1.16%	1.39%	0.52%	
Number of patches	93	93	98	97	
Median patch area (ha) (min–max)	82 (12–777)	77 (1–563)	56 (1–563)	58 (1–563)	
Number of patches adjacent to clearing	93	93	98	97	
Median P/A ratio (m/ha) for patches adjacent to clearing	74.22	80.68	87.06	86.37	

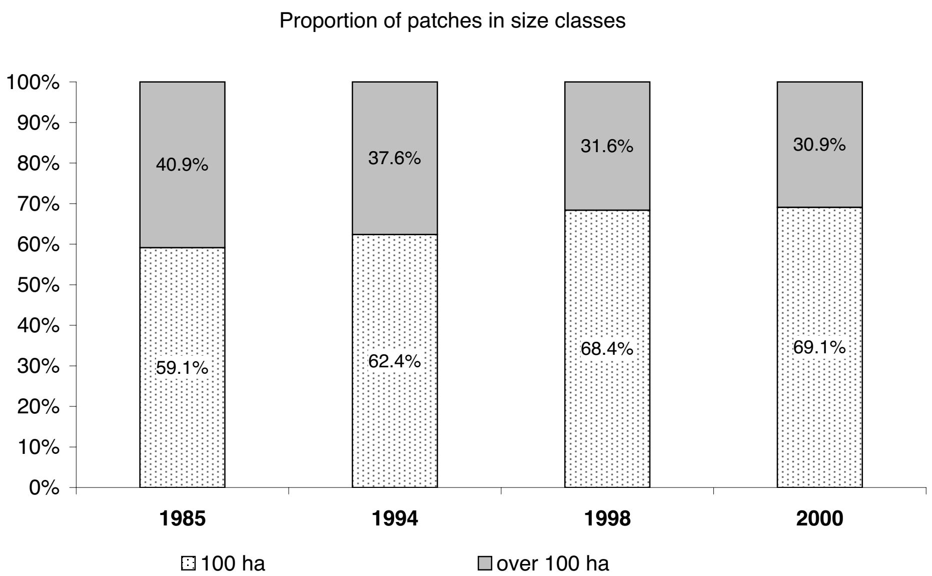

Fig. 31. The proportion of patches of P8: Belah Woodlands in each of two size classes.

Type P9: Open Shrublands and Woodlands

Description

This vegetation type occurs as open shrublands and woodlands which are typically very open and patchy. Canopy species include *Casuarina cristata, Eucalyptus coolabah, Eucalyptus largiflorens* and *Eucalyptus populnea* subsp. *bimbil*. It is found on grey clays on flats, open depressions, and gentle rises. The distribution of Open Shrublands and Woodlands is concentrated in the western third of the study area in the Castlereagh-Barwon province with lesser occurrences in the Northern Outwash and Northern Basalts provinces.

Stands of P9: Open Shrublands and Woodlands exhibit evidence of previous disturbance including thinning using a variety of techniques, ring-barking, poisoning and tree felling. The woody vegetation observed during field surveys for vegetation mapping was frequently young regrowth (Sivertsen & Metcalfe unpublished data). Remaining stands will now be over 13 years old with some in excess of 20 years old.

Clearing

Open Shrublands and Woodlands was the most heavily cleared of the extensive vegetation types in the study area and its rate of loss exceeded the overall rate of vegetation loss for the study period. 41 875 ha, or 22.4% of the mapped 1985 extent, were cleared (Table 20). The highest clearing rate was in the period ending 1998 while the rate fell by about 70% in the subsequent period.

Fragmentation

Patches of Open Shrublands and Woodlands became more numerous, smaller and more prone to edge effects over the study period. Minimum and maximum patch sizes decreased and there was a very marked reduction in the median size (Table 20). The proportion of patches in the smallest size class of up 100 ha increased by about ten times over the study period (Fig. 32) at the expense of the largest size classes. By the end of the study all patches were adjacent to clearing and their vulnerability to edge effects, as measured by perimeter to area ratio, had increased.

Table 20. Results for P9: Open Shrublands and Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	186 604	164 875	147 219	144 729	
Area cleared (ha)	-	21 729	17 656	2490	**41 875**
Area cleared (% 1985 vegetation)	-	11.6%	9.5%	1.3%	**22.4%**
Average annual clearing rate (ha/yr)	-	2414	4414	1245	**2792**
Average annual clearing rate (as % 1985 vegetation)	-	1.29%	2.37%	0.67%	**1.50%**
Average annual clearing rate (as % previous area)	-	1.29%	2.68%	0.85%	
Number of patches	105	156	213	223	
Median patch area (ha) (min–max)	1054 (41–14 011)	362 (1–11 573)	127 (1–7899)	95 (1–7899)	
Number of patches adjacent to clearing	103	156	213	223	
Median P/A ratio (m/ha) for patches adjacent to clearing	17.25	28.19	55.52	64.02	

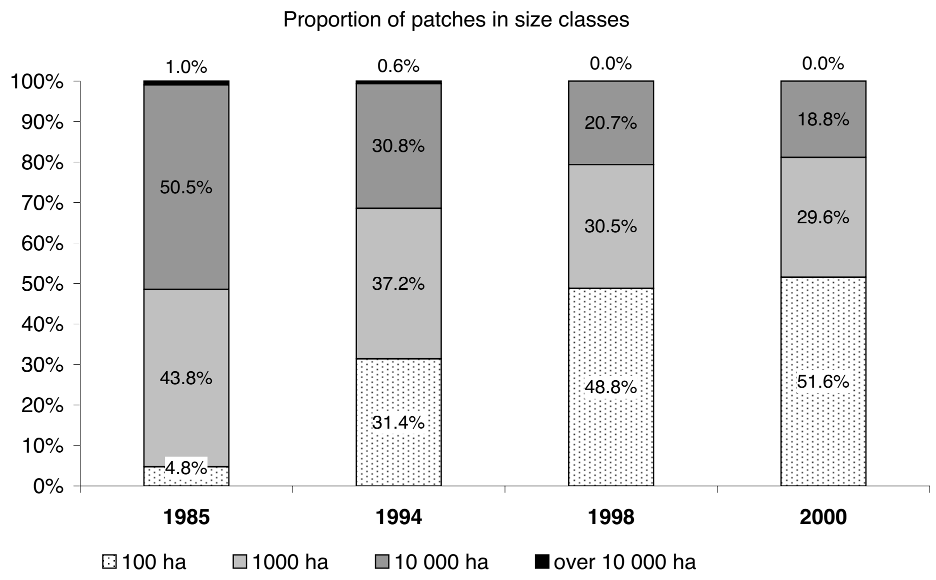

Fig. 32. The proportion of patches of P9: Open Shrublands and Woodlands in each of four size classes.

Type P10: Brigalow Woodlands

Description

This vegetation type varies in structure from mid-high woodlands to tall open forests. Canopy species include *Acacia harpophylla* with pockets of *Casuarina cristata*, and *Eucalyptus populnea* subsp. *bimbil*. It is found on brown clays of flats that are shallowly gilgaied. Most occurrences are in the northern half of the study area in the Northern Outwash and Northern Basalts Provinces with minor occurrences in the Castlereagh-Barwon Province.

Once extensive through what was known as the Brigalow Belt, Brigalow Woodlands were substantially cleared from the 1960s onwards. From an estimated extent of 250 000 ha (Pulsford 1984 cited in Benson 1999) only 5790 ha were present in 1985 (Sivertsen & Metcalfe unpublished).

Clearing

There was further clearing of Brigalow Woodlands during the study period with 823 ha, or 14.2% of the mapped 1985 distribution, being cleared (Table 21). The highest clearing rate occurred in period ending 1998 with a substantial reduction in the rate for the subsequent period.

Fragmentation

All remaining patches of Brigalow Woodlands are small. No patches are over 700 ha and half are less than 100 ha. The period ending 1994 saw a decrease in median patch size (Table 21) and an increase in proportion of patches in the smallest size class (Fig. 33). The very high perimeter to area ratios for all periods are a result of the generally small patches and indicate a high vulnerability to edge effects.

Table 21. Results for P10: Brigalow Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	5792	5276	4994	4969	
Area cleared (ha)	-	516	282	25	**823**
Area cleared (% 1985 vegetation)	-	8.9%	4.9%	0.4%	**14.2%**
Average annual clearing rate (ha/yr)	-	57	70	13	**55**
Average annual clearing rate (as % 1985 vegetation)	-	0.99%	1.22%	0.22%	**0.95%**
Average annual clearing rate (as % previous area)	-	0.99%	1.34%	0.25%	
Number of patches	37	39	40	41	
Median patch area (ha) (min–max)	119 (11–682)	83 (11–618)	81 (11–606)	78 (11–606)	
Number of patches adjacent to clearing	37	39	40	41	
Median P/A ratio (m/ha) for patches adjacent to clearing	103.20	110.68	109.98	109.29	

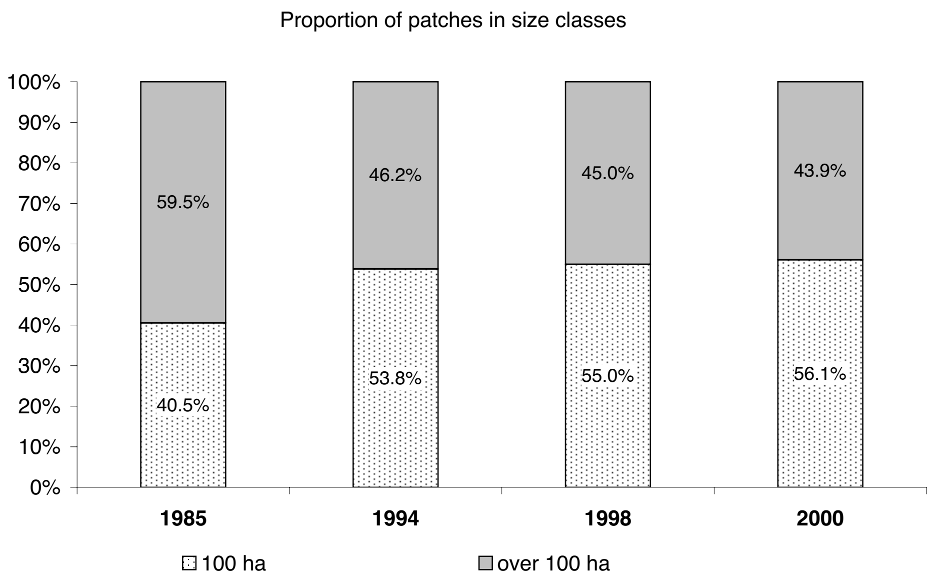

Fig. 33. The proportion of patches of P10: Brigalow Woodlands in each of two size classes.

Type F4: Yetman Footslopes Complex

Description

This is a complex type with sub-units too small to map at the 1: 250 000 scale used by Sivertsen and Metcalfe (unpublished). It varies in structure from tall to very tall woodlands and open forests. Canopy species include *Angophora costata, Eucalyptus chloroclada* and *Eucalyptus blakelyi* with some *Eucalyptus melanophloia* and *Callitris glaucophylla* also present. It occurs on siliceous and earthy sands associated with sandy streamlines and flats in the extreme east of the study area in the Northern Outwash and Northern Basalts provinces.

Clearing

The only clearing recorded for Yetman Footslopes Complex was 19 ha, or 2.8% of the 1985 mapped extent, in the period ending 1994 (Table 22).

Fragmentation

The number and size of patches remained stable throughout the study period.

Table 22. Results for F4: Yetman Footslopes Complex

	1985	1994	1998	2000	Overall
Remaining extent (ha)	697	677	677	677	
Area cleared (ha)		19	0	0	**19**
Area cleared (% 1985 vegetation)	-	2.8%	-	-	**2.8%**
Average annual clearing rate (ha/yr)		2	-	-	**1**
Average annual clearing rate (as % 1985 vegetation)		0.31%	-	-	**0.19%**
Average annual clearing rate (as % previous area)		0.31%	-	-	
Number of patches	8	8	8	8	
Median patch area (ha) (min–max)	42 (13–364)	41 (13–364)	41 (13–364)	41(13–364)	
Number of patches adjacent to clearing	8	8	8	8	
Median P/A ratio (m/ha) for patches adjacent to clearing	75.64	75.64	75.64	75.64	

Type H5: Yetman Hills Complex

Description

This is a complex type with sub-units too small to map at the 1: 250 000 scale used by Sivertsen and Metcalfe (unpublished). Its structure varies from mid-high open woodlands to open forests. A variety of canopy species are present including *Callitris glaucophylla, Allocasuarina luehmannii, Angophora costata, Eucalyptus crebra, Corymbia dolichocarpa, Eucalyptus dealbata* and *Eucalyptus melanophloia*. It grows predominantly on sandy red and yellow earths and siliceous sands on crests, slopes and flats. Most of its remaining extent is in Northern Basalts province in the far north- east of the study area with lesser occurrences in the Northern Outwash and Peel provinces.

Clearing

2422 ha of Yetman Hills Complex, or 14% of the 1985 mapped extent, were cleared over the study period (Table 23). Most clearing occurred in the period ending 1994.

Fragmentation

Patch sizes were relatively stable over the study period (Table 23, Fig. 34). All patches were adjacent to clearing and there was a modest increase in perimeter to area ratio.

Table 23. Results for H5: Yetman Hills Complex

	1985	1994	1998	2000	Overall
Remaining extent (ha)	17 201	15 030	14 892	14 779	
Area cleared (ha)	-	2172	137	113	**2422**
Area cleared (% 1985 vegetation)	-	12.6%	0.8%	0.7%	**14.1%**
Average annual clearing rate (ha/yr)	-	241	34	57	**161**
Average annual clearing rate (as % 1985 vegetation)	-	1.40%	0.20%	0.33%	**0.94%**
Average annual clearing rate (as % previous area)	-	1.40%	0.23%	0.38%	
Number of patches	12	15	15	15	
Median patch area (ha) (min–max)	157 (30–9598)	145 (26–8550)	145 (26–8550)	145 (26–8550)	
Number of patches adjacent to clearing	12	15	15	15	
Median P/A ratio (m/ha) for patches adjacent to clearing	35.20	39.65	39.65	39.65	

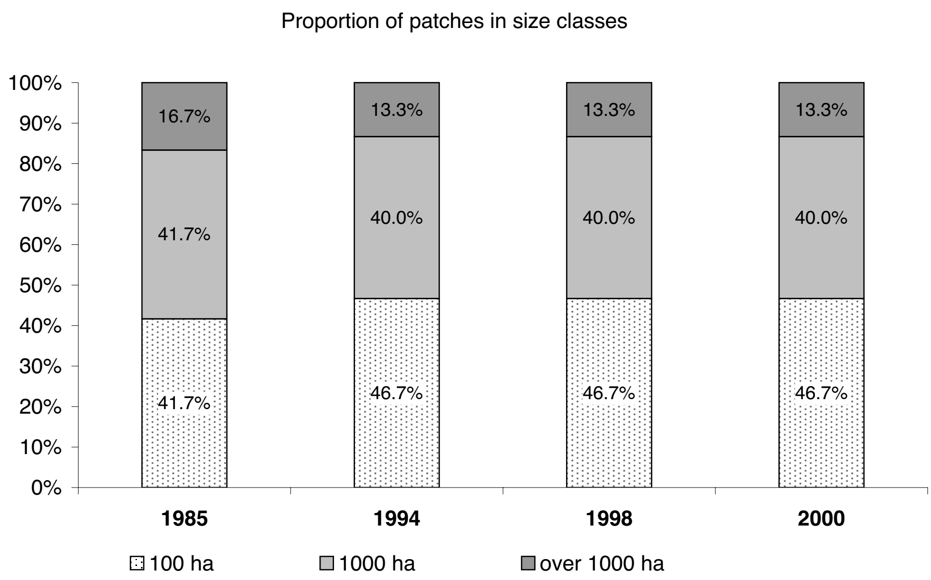

Fig. 34. The proportion of patches of H5: Yetman Hills Complex in each of three size classes.

Type H8: Basalt Hills

Description

This vegetation type forms mid-high open woodland and shrubland. Canopy species include *Casuarina cristata, Eucalyptus populnea* subsp. *bimbil, Callitris glaucophylla, Corymbia dolichocarpa*, and *Brachychiton populneus*. Seven small remnants were mapped on basalt hills by Sivertsen and Metcalfe (unpublished) on the eastern margin of the study area in the Northern Basalts province.

Clearing

The only clearing recorded for Basalt Hills was in the period ending 1998 with 146 ha, or 8.9% of the 1985 mapped extent, being cleared (Table 24).

Fragmentation

The size of the largest patch decreased in the period ending 1998 but otherwise patch sizes remained stable as did the median perimeter to area ratio.

Table 24. Results for H8: Basalt Hills

	1985	**1994**	**1998**	**2000**	**Overall**
Remaining extent (ha)	1649	1649	1503	1503	
Area cleared (ha)	-	0	146	0	**146**
Area cleared (% 1985 vegetation)	-	-	8.9%	-	**8.9%**
Average annual clearing rate (ha/yr)	-	-	36	-	**10**
Average annual clearing rate (as % 1985 vegetation)	-	-	2.21%	-	**0.59%**
Average annual clearing rate (as % previous area)	-	-	2.21%	-	
Number of patches	7	7	7	7	
Median patch area (ha) (min–max)	127 (28–702	127 (28–702)	127 (28–556)	127 (28–556)	
Number of patches adjacent to clearing	7	7	7	7	
Median P/A ratio (m/ha) for patches adjacent to clearing	43.95	43.95	43.95	43.95	

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