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Factors influencing the loss of an endangered ecosystem in an urbanising landscape: a case study of native grasslands from Melbourne, Australia

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Abstract

Over the past two decades, the decline and destruction of native grasslands in Australian cities has intensified. In Melbourne, large remnants of this endangered vegetation type have been subdivided and destroyed by urban development while linear reserves are being degraded by changes to management practices. To analyse fragmentation patterns we developed a temporal dataset spanning the period 1985–2000 that recorded the extent and distribution of native grassland patches in western Melbourne. Of the 7230 ha of native grassland present in 1985, 1670 ha (23%) were destroyed by development and 1469 ha (21%) were degraded to non-native grassland by 2000. There were fewer patches and greater distance between patches in 2000 than in 1985, indicating that fragmentation has intensified. Logistic regression models were used to determine the probabilities that a patch would be destroyed, degraded or remain as native grassland. Patches that were privately or government owned, close to major roads and close to Melbourne were more likely to be destroyed while patches close to streams or on railway land had a lower probability of destruction. Patches with high perimeter to area ratios had a higher probability of being degraded. Biological significance ranking was also an important explanatory variable determining patch fate but areas of higher significance were not necessarily preserved. The preservation and ecological management of grasslands in Australia is a high conservation priority and utilising landscape and societal based predictors of threat can help set priorities for the protection and management of sites.

Keywords: Grassland; Landscape ecology; Urbanisation; Fragmentation; Land-use change

1. Introduction

There are a wide variety of models of how cities develop including concentric zone, non-concentric zone, sector model, multiple nuclei, urban realms model and diffusion-limited aggregation that have assessed social and economic impacts of different urban structure (Hall, 1998), but researchers have not attempted to assess the impacts of these different models on the preservation of biologically significant ecosystems. The conversion of agricultural or natural areas to urban use is caused by a complex set of physical, social and economic interactions. Population density, topography and the proximity of land to roads, markets and population centres have been shown to be important physical attributes driving these land-use changes

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(Bradshaw and Muller, 1998; Wear et al., 1998; Kline et al., 2001; Lo and Yang, 2002; Cheng and Masser, 2003). The creation of a risk assessment model for biologically significant ecosystems in urbanising areas using both site and landscape characteristics would provide policy makers, managers and conservationists with another tool to prioritise preservation efforts.

In Victoria, Australia, lowland native grassland is recognised as one of the State's most endangered vegetation types (Stuwe, 1986; Frood and Calder, 1987; Barlow and Ross, 2001), where it is listed as a threatened community (Muir, 1994) under Victorian legislation and has been nominated as a critically endangered community under Federal legislation. This status is repeated across south eastern Australia where over 99.5% of the original lowland grassland vegetation has been destroyed or greatly altered leaving only approximately 10,000 ha relatively intact (McDougall, 1994).

The concern for the loss of temperate native grasslands in Victoria is not new. Charles Sutton (1916), a prominent naturalist of the early 1900s, made the following statement about the Basalt Plains grasslands west of Melbourne:

> "The area is not favoured for residential purposes, and has not much been built over; but it has been put so thoroughly to pastoral and agricultural uses that hardly any part remains in the virgin state".

Sutton's observations highlight the early transformation of native grasslands to agricultural use soon after European settlement of western Victoria in the late 1830s. Large flocks of sheep were introduced that preferentially grazed some species, compacted the soil and facilitated the introduction of weeds. After the 1850s, there was a sharp rise in the area under cultivation and continuous cropping (Conley, 1983). However, the widespread application of fertilisers and sowing of introduced species for pasture improvement, and the use of heavy machinery associated with the intensification of farming activities after the Second World War probably led to the destruction of more native grasslands than ploughing in the nineteenth century (Kirkpatrick et al., 1995). However, on the outskirts of cities and towns where urban expansion was planned, such agricultural investment was often not undertaken and native grassland persisted (Frawley, 1995). By the 1980s, most of the high quality Australian temperate native grasslands were confined to relict pockets in ungrazed areas close to cities and towns (Groves, 1979). The outskirts of two of Australia's capital cities, Melbourne and Canberra, as well as several regional cities, still contain significant amounts of remnant grassland (Stuwe, 1986; Lunt, 1990; Benson, 1994; ACT Government, 1997; Morgan, 1998).

Stuwe (1986) surveyed the native grasslands of western Victoria in 1984–1985 and found that the area immediately north and west of Melbourne, encompassed many of the best, large remnants of temperate lowland grassland in Victoria. Since the 1980s, the western and northern suburbs of Melbourne have experienced a period of sustained development characterised by high rates of population growth and accompanying new residential and industrial development (State of Victoria Department of Infrastructure, 2000). Since 1985, Melbourne's population has increased from 2.9 to 3.2 million people (Australian Bureau of Statistics, 2001). During 2000, local government areas in the basalt plains experienced population increases of up to 45% (Australian Bureau of Statistics, 2001). This level of population increase, along with the associated development, is expected to continue (State of Victoria Department of Infrastructure, 2000).

In addition to the threat of development, native grasslands are being degraded due to weed invasion. A number of factors including drainage of nutrient rich water from adjacent agricultural land or urban areas, soil disturbance associated with vehicle access, and the activities of road and rail management agencies and utility companies appear to give non-indigenous species a competitive advantage over indigenous grassland species (Kirkpatrick et al., 1995). Non-indigenous species are also favoured by inappropriate management (Lunt and Morgan, 1999a,b), particularly a lack of biomass removal caused by the absence of burning or grazing, that causes a build up of dead plant material which decomposes releasing nutrients that favour weed growth (Morgan and Lunt, 1999).

The objectives of this study were: (1) to gain an understanding of the impact of development and weed invasion on the persistence of temperate native grasslands in Melbourne over a 15-year period and (2) to use the changes in the number and sizes of native grassland patches to develop a model that utilises measures of patch characteristics, landscape fragmentation, distance to roads, water and city centre, ownership, and biological significance rating to assess the vulnerability of existing grasslands in the region to future destruction or degradation.

2. Methods

2.1. Study area

The study area comprises 188,000 ha, most of which occurs on a Quaternary basalt plain underlying the northern and western of suburbs of Melbourne (Fig. 1). The plain was formed by sheet lava flows from a number of eruption points in the region (Conn, 1993). Weathering of the basalt parent material has produced heavy clay soils (McDougall et al., 1994), that become hard and cracked in summer, limiting tree growth (Geraghty, 1971). Low rainfall, typically 500–700 mm per year (Bureau of Meteorology and Walsh, 1993), has resulted in the development of an extensive dry tussock grassland dominated by *Themeda triandra* and *Austrodanthonia* species (Willis, 1964; Conn, 1993). Land use is predominantly urban but substantial areas of stock grazing and other non-intensive uses exist on the urban–rural fringe.

2.2. Fragmentation patterns (1985–2000)

We created an extensive database of all the grasslands within the study area in both 1985 and again for 2000. To determine the extent and location of grasslands in 1985 we examined 29 references published between 1985 and 2000 documenting the native grasslands of Melbourne. Many of these studies mapped

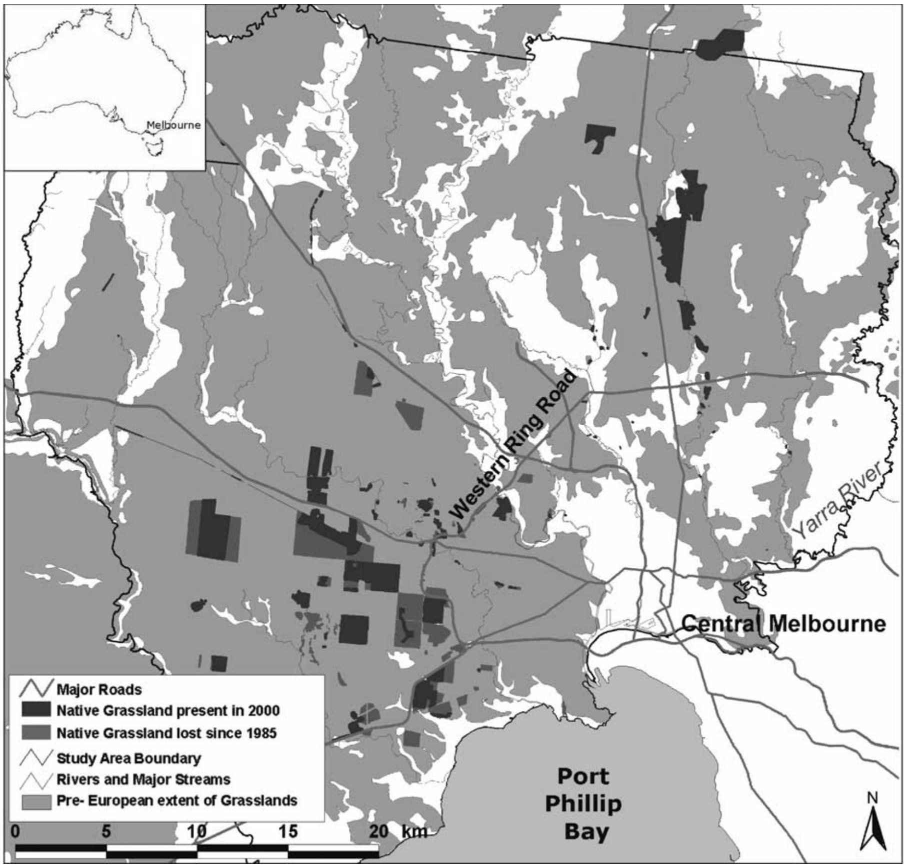

Fig. 1. Map of the study area showing the patches of native grassland present in 1985 and those remaining in 2000. The pre-European extent of native grasslands, major roads and steams in the Melbourne metropolitan region are also illustrated.

and described multiple grassland sites while others focused on one site. The published literature was supplemented by database records and geographic information system (GIS) data sets documenting grassland sites compiled by the Victorian Department of Sustainability and Environment as well as knowledge from local experts. These data were combined to create a GIS 1985 map of the remnant grasslands of Melbourne.

The extent of native grassland in 2000 was determined by field checking between August and October 2000 all patches identified as native grassland on the 1985 map. Patches were classified into one of three condition classes: (1) native grassland, (2) developed for housing or industry so that the patch was considered destroyed, or (3) degraded by weed invasion or other processes to a grassland dominated by non-native plants. Whether a patch remained as native grassland or had been degraded to non-native grassland was based on the diversity and abundance of native and introduced plants. Native grassland patches had at least 40% foliage cover of native species and at least five native species present. Patches were only considered degraded if there was greater than 60% foliage cover of non-native species over their entire area. Unlike developed patches, those classified as degraded could theoretically be restored to native grassland given adequate time and resources. These data were combined to create a GIS map of the remnant grasslands of Melbourne present in 2000. The rate of grassland destruction over time by the various forms of urban development was determined by using a variety of sources including grassland survey reports, maps indicating land use change, expert knowledge and Victorian Department of Sustainability and Environment databases.

Using GIS, we were able to quantify the changes in grassland sites between 1985 and 2000. Metrics were calculated at a patch and class level. Patch level metrics used were: area, perimeter, perimeter to area ratio and nearest neighbour distances. Class metrics quantified the amount and distribution of grassland in the landscape. These were: class area, percentage of landscape, number of patches, mean nearest neighbour distance, mean patch size and mean perimeter to area ratio.

2.3. Predictors of patch status in 2000

Several characteristics of the grassland patches in 1985 were analysed to determine if they affected the ultimate fate of the patches over the 15-year period of the study. These characteristics included size of the patch, shape of the patch (perimeter:area ratio), distance to Melbourne's central business district, distance to nearest major road (freeways or highways), distance to third or higher order stream, biological significance of the patch, and ownership (tenure) (Table 1). Because of the correlation between patch area and patch

Table 1
Grassland patch characteristics in 1985 used in the logistic regression analysis to determine which factors were important in determining the probability that a patch will be destroyed or degraded

Continuous variables	Notes
Patch area	
Patch perimeter to area ratio	
Distance to Melbourne's central business district	Measured in a direct line
Distance to major road	Defined as freeways or highways. Measured in a direct line
Distance to stream	Defined as nearest third-order or greater stream as these were more likely to flow permanently. Measured in a direct line
Categorical variables	
Biological significance	Four classes: local, regional, state, and national
Ownership (tenure)	Four categories: Freehold—owned by private individuals or companies Rail—land used as a railroad easement Commonwealth—owned by the Australian government, formerly used for defence and other purposes Other, drainage reserve, road reserve, etc.

perimeter:area ratio, we used patch area in the analysis of the factors influencing development and perimeter:area ratio for the analysis of factors influencing patch degradation.

The class of tenure or ownership of the grassland patches was compiled from the original survey reports, personal observation and the knowledge of botanists familiar with Melbourne's grasslands. We classified the various tenures into four categories (defined in Table 1) based on the most common form of ownership of the grassland patches in the study area. "Other" includes all patches of unknown ownership and those classes of tenure with too few examples to be analysed, third-order road reserve, drainage reserve. Because it is a mixed category it was not used for the regression analysis.

Due to the retrospective nature of this study, it was necessary to assign the biological significance of the grassland patches as assessed by the authors of the reports used to develop the maps of native grassland extent. Typically, authors assessed biological significance subjectively using a combination of floristic diversity, rarity of the species present and the overall condition of the grassland. The most common classification system employed where patches were deemed to be of national, state, regional or local significance was adopted for this study (McDougall, 1987; Department of Conservation and Environment, 1990). Patches assessed using classification systems that differed from this were incorporated into the above scheme using the classification criteria described in each study. Where sites were assessed by multiple reports, the biological significance ranking ascribed to the sites in the year closest to 1985 was used in the analyses.

To assess which factors were important in determining the probability of a patch being destroyed (i.e. developed) between 1985 and 2000, we created a logistic regression model that included all the variables listed above (Table 1; Hosmer and Lemeshow, 2000). This analysis tested both the original and log transformed values of the continuous variables (area, distance to Melbourne's central business district, roads and streams) and two categorical variables (land ownership and biological significance). To assess which factors were important in determining the probability of a patch being degraded (i.e. weed invaded), we used the same variables but substituted patch perimeter:area ratio for patch area. These models were also used to predict which grasslands were exposed to the greatest threat of destruction and degradation. To enable comparisons between models, predictions were based on a model using a privately-owned patch of native grassland of state biological significance with all other variables except the variable being tested (ie, alternately distance to major road, distance to Melbourne's central business district and distance to stream) kept constant at their mean.

3. Results

3.1. Fragmentation patterns (1985–2000)

In 1985, 7230 ha (3.8%) of the study area was native grassland. By 2000, this had been reduced to 4071 ha (2.2%). Therefore, 56% of the grassland that existed in 1985 remained 15 years later in 2000. During this period, 1670 ha of native grassland (23%) were destroyed by urban development and 1469 ha (21%) were degraded to non-native grassland.

The number of grassland patches was reduced from 192 in 1985 to 122 in 2000. Of the 70 patches no longer present, 46 were totally destroyed by urban development while an additional 49 were classified as degraded to non-native grassland. The 122 patches remaining as native grassland in 2000 are not all the same size as in 1986; 19 patches were partially destroyed by development and a further 34 were partially degraded. This has caused the creation of 25 new patches; four due to development and 21 due to weed invasion.

There were fewer grassland patches and a greater distance between remnant patches in 2000 than in 1985 indicating that significant fragmentation of the grasslands has occurred over the 15-year study period. The average size of grassland patches has decreased between 1985 and 2000, from 37.6 to 33.4 ha (Table 2). Patches of all sizes present in 1985 have been destroyed or degraded (Fig. 2). The perimeter:area ratios of the remaining native grassland patches were similar for 1985 and 2000 landscapes (7.0 and 8.0, respectively) due to the loss of many small sites. The average distance between patches has increased from 661 to 794 m. The rate of loss and fragmentation of Melbourne's grasslands has not been

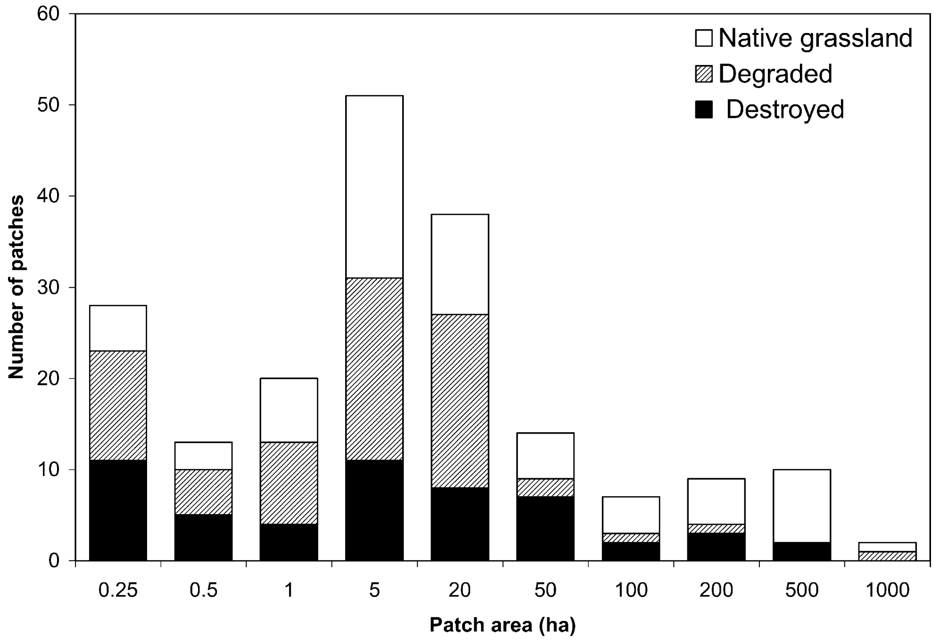

Fig. 2. Frequency of patches that have been destroyed, degraded or remained as native grassland between 1985 and 2000 by patch size.

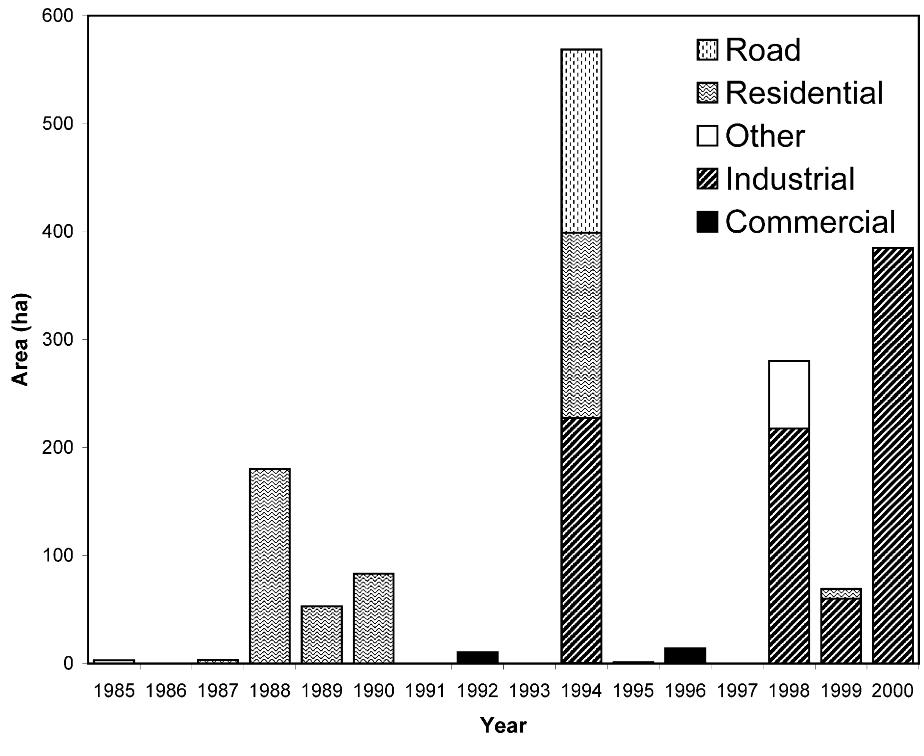

Fig. 3. Area of native grassland destroyed by various forms of development between 1985 and 2000.

Table 2
Changes in class metrics between 1985 and 2000

	1985	2000		
	Native grassland	Native grassland	Destroyed	Degraded
Total area (ha)	7230	4071	1690	1469
Percentage of landscape	3.8	2.2		
Number of patches	192	69	53	70
Mean nearest neighbour distance (m)	661	794		
Mean patch size (ha)	37.6	33.4	26.0	11.1
Mean perimeter to area ratio (m)	7.0	8.0	4.9	11.2

constant over this period (Fig. 3). Instead it was characterised by periods when large areas of native grassland were developed for houses, industry or roads, and periods of stability when little grassland was developed. Large areas of native grassland were destroyed during the periods 1988–1990, 1994 and 1998–2000.

3.2. Predictors of patches being destroyed by 2000

Grassland patches closer to the central business district were significantly more likely to have been destroyed by development than those more distant. Similarly, patches further from major roads had a lower probability of being destroyed (Table 3). Patches destroyed by development were, on average 16 km from Melbourne's central business district while those that remained as native grassland or became degraded were on average 20 km from the central business district. Grassland patches that were destroyed were on average 1200 m from a major road while those that remained as native grassland or became degraded were on average 2700 m from a road. In contrast, those patches furthest from streams had a higher probability of being destroyed.

The influence of ownership and biological significance on the probability of a patch being destroyed were not as straight forward. The biological significance of the site was a statistically significant variable in explaining whether it was developed. Sites of Local Biological Significance had a higher probability of being destroyed than either patches of Regional or National significance. State significance appears to have little or no impact on the probability of a patch being destroyed or preserved (Table 3). Freehold and Commonwealth government owned patches had a higher probability of being destroyed than grasslands along railway easements.

Table 3
Influence of patch characteristics in 1985 on the probability of the patch being destroyed in 2000

Patch characteristic	Regression co-efficient	Standard error	*P*-values
Patch Area	−0.1667	0.1352	0.2087
(ln) Distance to central business district	−3.6975	1.0385	<0.0005
(ln) Distance to Major Road	−0.8774	0.2186	<0.0005
(ln) Distance to stream	0.9532	0.2636	<0.0005
Biological significance			<0.05
Local	0.7785	0.8740	
Regional	−1.0559	0.8414	
State	0.1096	0.8800	
National	−0.9772	1.1969	
Tenure			<0.01
Freehold	1.6771	0.7503	
Railroad	−1.4940	1.0716	
Commonwealth	1.4710	0.7473	

Table 4
Influence of patch characteristics in 1985 on the probability of the patch being degraded in 2000

Patch characteristic	Regression co-efficient	Standard error	*P*-values
Patch perimeter:area ratio	0.6291	0.2619	<0.05
(ln) Distance to central business district	−0.0782	0.8333	0.925240
(ln) Distance to major road	−0.1563	0.2307	0.497719
(ln) Distance to stream	−0.1433	0.1741	0.409360
Biological significance			<0.05
Local	1.4438	1.0045	
Regional	1.5607	0.8916	
State	−0.1272	1.0321	
National	1.4215	1.1294	
Tenure			<0.05
Freehold	1.5118	0.6367	
Railroad	1.6419	0.9695	
Commonwealth	−0.3556	0.8851	

3.3. Predictors of patches being degraded by 2000

Grassland patches with high perimeter:area ratios (ie, small patches) had a higher probability of being degraded (Table 4). Tenure and biological significance were both significant explanatory variables for patch degradation. Freehold and railroad easement patches had a higher probability of being weed invaded than grasslands owned by the Commonwealth government. Sites of Local, Regional and National significance were more likely to become weed invaded than sites of State significance (Table 4).

3.4. Identifying patches at greatest risk of being destroyed or degraded

The models can be used to predict the probability that a given grassland patch will be destroyed or degraded based on its location in Melbourne. Fig. 4 shows the relationship between the distance from Melbourne's central business district, major roads and third-order streams with the probability that a grassland patch will be destroyed by development or lost to degradation.

The probability of destruction was very high close to major roads and the central business district, declining at a relatively constant rate with distance from central business district and at a decreasing rate with distance from major roads (Fig. 4). The probability of destruction increased asymptotically with increasing distance from streams. The probability of loss due to degradation remains constant with distance from the central business district (just below 20%), and relatively constant with distance from major roads and streams (around 40%). However, there is a small initial decline associated with the higher probability of degradation in close proximity roads and streams, probably because they may act as corridors for weed dispersal. Our model predicts that patches have a greater than 50% probability of being destroyed if they are less than 22 km from the central business district, less than 3.5 km from a major road and further than 800 m from a third-order or higher stream.

4. Discussion

4.1. Landscape fragmentation between 1985 and 2000

The grasslands of Melbourne's Western Plains have become significantly more fragmented over the past 15 years due to the destruction and degradation of remnants. In 1985, there were 192 remnant patches of grasslands covering over 7200 ha, but in the last 15 years there has been a loss of 70 patches (36.5%) resulting in a 44% reduction in remnant grassland area. A total of 1690 ha has been destroyed by development and 1469 ha have been lost to weed invasion between 1985 and 2000 leaving 4071 ha as native grassland.

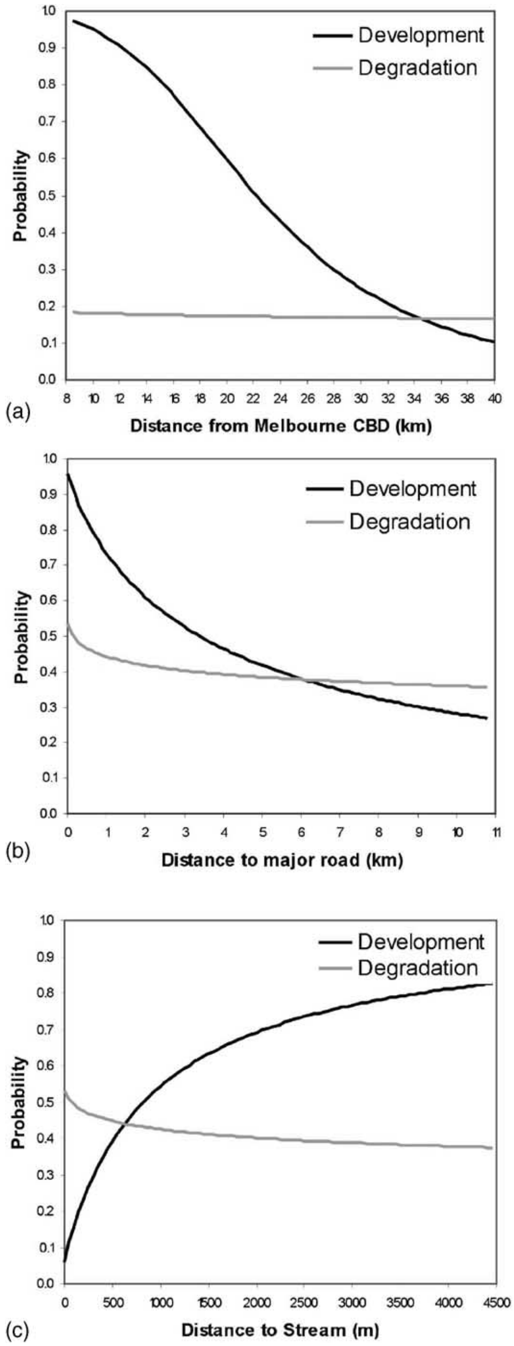

Fig. 4. The probability of a patch being destroyed by development or degraded with (a) distance to the Melbourne central business district, (b) distance to major road and (c) distance to third-order or higher stream.

Our study highlights the continuing decline of grassland in the study area reported by McDougall and Kirkpatrick (1994). They resampled grassland sites 10 years after the original survey (Stuwe, 1986) and found that 44% of the sites had been destroyed, severely degraded or earmarked for destruction and that half of the remaining "intact" sites had been reduced in size or degraded to some extent.

A similar study in Canberra examined the fate of 40 grassland sites over a 16-year period (ACT Government, 1997). Between 1980 and 1996, 17.5% were totally lost 37.5% were modified or severely degraded, 20% were partially lost, and 25% remained at a similar size without significant degradation (Sharp and Shorthouse, 1996; ACT Government, 1997). By comparison, Melbourne has experienced a loss of 36% of the grassland patches and a 44% reduction in grassland area over a 15-year period (1985–2000) while 70% of Canberra's grassland patches have been either totally or partially destroyed in 16 years (1980–1996). Although Canberra is a younger metropolitan area than Melbourne, the loss and fragmentation of its remnant native grasslands appears to be occurring at a similar, if not more, rapid rate.

The rate of grassland loss in our study is high but it is much less than that found for some European calcareous grasslands. In the Swiss Jura mountains, nearly three-quarters of the rare, species-rich, nutrient-poor, grasslands were completely destroyed and the remaining sites were considerably reduced in area over a 35-year period between 1950 and 1985 (Fischer and Stocklin, 1997). While in the of the South-Limburg region of the Netherlands only 20 chalk grassland fragments, between 0.5 and 5 ha in size, remain of what was once an extensive area of grassland due to agricultural intensification (WallisDeVries et al., 2002).

The loss and reduction in size of the Melbourne's remnant grassland patches have not only resulted in a decrease in grassland area, but has also increased the between patch distance. This level of fragmentation not only reduces the amount of grassland habitat available for native plants and animals, but also increases the isolation of the habitat that remains. Increased isolation of grassland patches may impede the movement of animals between patches (Dorrough and Ash, 1999) and lead to local extinction of species (Seebeck, 1984; Collinge, 2000). Fragmentation increases the ratio of edge to interior habitat, encouraging invasion by weeds (Morgan, 1998) and increasing predation on birds and mammals (Herkert, 1994; Bock et al., 2002). Habitat fragmentation can also affect the reproductive success (Menges and Dolan, 1998; Morgan, 1999), persistence (Leach and Givnish, 1996; Fischer and Stocklin, 1997) and dispersal ability (van Dorp et al., 1997; Soons and Heil, 2002) of grassland plant species, by changing the plant's physical environment and its interactions with pollinators (Lennartsson, 2002).

4.2. Predictors of patches being destroyed by 2000

Much has changed since Sutton (1916) wrote about Melbourne's grasslands. Residential, industrial and major project developments have been identified as an immediate threat to the persistence of remnant grasslands for many years by community groups (Rayner, 1992; Ross, 1993), scientists (Groves, 1979) and the Victorian government (Department of Conservation and Environment, 1990; Department of Natural Resources and Environment, 1997). Many patches of native grassland with high biodiversity values have been destroyed by development since 1986 (Urban Land Authority, in literature; Meredith et al., in literature; Yugovic et al., in literature). Our results indicate that patches were more likely to be destroyed by development when they were closer to the central business district of Melbourne and were close to highways and freeways. They were less likely to be developed if they were close to streams or on railway land.

The higher probability that a patch closer to the central business district would be developed reflects the concentric pattern of Melbourne's of growth. It also supports the findings of Wear et al. (1998) that position on the urban–rural gradient has a significant impact on land-cover change and resulting landscape patterns.

Proximity to roads has been shown to be an important driver of land cover change in many studies (Turner et al., 1996; Wear et al., 1998) and the presence of highways has been found to be strongly correlated with a change from natural and agricultural "green" areas (Lo and Yang, 2002). Due to the ubiquitous nature of the road network in urban areas, construction of a small or local road is unlikely to alter transportation costs and trigger large scale or detectable landscape changes. In urban areas it would take the construction of a major new road to change transportation costs sufficiently to trigger major land use change.

In Melbourne, the Western Ring Road (Fig. 1) is a freeway linking three existing radial freeways that was built in stages from 1992 to 1997. Its construction caused the direct destruction and fragmentation of a number of patches of native grassland along the route (Meredith et al., in literature) and may also have facilitated the destruction of other native grasslands in the region surrounding the road. The western and northern western regions of Melbourne have experienced a sustained growth in the level of investment in factory construction from 1991 (O'Connor, 1998). This activity corresponds with the announcement (Parliament of Victoria 1991) and subsequent construction and opening of the Western Ring Road. The completion of the road has made some industrial locations in western and north-western Melbourne much more accessible by road (O'Connor and Rapson, 1996). The subsequent loss of 226 ha of native grassland to industrial development in 1994, and similar amounts in later years, suggests that factory development triggered by the construction of a freeway contributed to the destruction of some of the last remnants of native grassland within metropolitan Melbourne.

Proximity to third-order streams was found to be significantly negatively correlated with the destruction of native grassland by development. This probably reflects a number of influences such as zoning or physical constraints on development. Some streams in the study area are likely to have planning restrictions on them due to flood risk, while other areas close to streams may be too steep to build on. It may also be due to the aesthetic appeal of including water courses in public open space reservations required in new housing subdivisions, and reserves in general.

Development has destroyed large amounts of native grassland on private land in Melbourne compared to other classes of ownership. This is expected due to the large amount of private land relative to other tenures but is also due to economic drivers and planning constraints associated with different types of land tenures. The potential financial gain of converting private native grassland to urban uses and the rising costs of farming in an increasingly urban landscape often encourage land owners to sell to developers. In many cases, this occurred decades prior to the land being developed. Other studies have found lower rates of change to non vegetated classifications (i.e. urban, agricultural) occurring on government owned land (Turner et al., 1996; Wear et al., 1998) compared with private land. Government ownership has not necessarily protected Melbourne's native grasslands. The destruction of grassland on land owned by the Commonwealth government reflects the recent push by Australian governments to raise funds by selling surplus land owned by their departments and agencies (Adam, 2001). Although some government owned grasslands have been incorporated into the reserve system, many sites previously owned by the Department of Defence were sold to developers when their use became incompatible with increasing urbanisation of the area. Planning restrictions have generally prevented the development of land zoned as railway, road and drainage reservations.

The loss of the once vast areas of native grasslands in Victoria and the need to preserve the grasslands around Melbourne have been recognised by government for many years (Forster et al., 1975; Western Suburbs Planning and Environment Action Program, 1983). A series of reports over the past two decades (McDougall, 1987) culminated in a conservation action plan for grassland sites in the Melbourne area based on their biological significance (Department of Conservation and Environment, 1990). This detailed the management actions, including possible reservation and purchase, required to preserve the sites identified. A number of sites have been purchased for reservation or have co-operative ecological management agreements in place with the private owners (Victoria Department of Natural Resources and Environment, 2001), but our study suggests that overall, attempts to conserve Melbourne's grasslands have not been successful. While it is expected that those sites with the lowest level of biological significance (local) would be developed in preference to those with higher levels of significance, the biological significance of those sites with second highest ranking (state) made little difference to the fate of the site. In fact, these sites were more likely to be developed than remain as native grassland.

4.3. Predictors of patches being degraded by 2000

The results of this study indicate that patches of native grassland with high edge to area ratios on privately owned land and railway easements are more likely to be degraded to non native grassland than other patches Railway easements have been shown to have a distinct suite of species, often of high conservation significance, when compared to the larger patches of native grassland subject to grazing by domestic stock (Stuwe and Parsons, 1977; Scarlett and Parsons, 1981; Lunt, 1995, 1997) Historically, railway easements have had little or no grazing and were managed by regular burning conducted to prevent fires caused by sparks from steam locomotives. The persistence of high quality native grassland on narrow railway easements, that were established in the nineteenth century, suggests that biological values can be maintained on patches with high edge to area ratios in the long term through ecologically appropriate management.

However, changes to the management of railway easements in recent years has been identified as the major threat to native grasslands on those easements (Govanstone et al., in literature; Ross, in literature, Craigie, in literature). Due to the introduction of diesel locomotives, railway easements are no longer burned and track maintenance formerly undertaken from the tracks is now largely conducted from the side of the tracks. Sites have been lost to weed invasion following the dumping of old ballast during track reconstruction works, depositing earth after clearing drains, herbicide spraying, mowing and slashing and the bulldozing of access tracks (Rayner et al., 1984) Other rail easements have been disturbed through the actions of utility companies that have laid cables or pipelines along the easements (N. Williams personal observation). Damage has primarily occurred because of inadequate communication between government authorities charged with protecting native grassland and those required to perform maintenance of the railway line. This has been exacerbated by the recent privatisation of Victorian rail lines and the subsequent employment of private contractors to perform maintenance duties that has led to further loss of several important sites (Craigie, in literature).

The probability of a site being degraded (i.e. weed invaded) was also not influenced by its biological significance with sites of local, regional and national significance having a high probability of becoming degraded. However, these results should be treated with caution as many of the sites of national significance were located on railway owned land and tenure has a more significant relationship than biological significance in explaining the probability of degradation (Table 4).

Current government conservation planning policy is to create a reserve system with an "emphasis on long-term viability, thus there (is) a concentration on larger sites away from urban areas" (Department of Natural Resources and Environment, 1997). This policy assumes that urban grassland reserves are not viable in the long term, despite evidence that with appropriate resources and management they are able to persist and maintain the majority of their biological values (Williams and Morgan, unpublished data). The grasslands around Melbourne are floristically distinct to those in rural areas in western Victoria and contain threatened species not found at other sites. Railway reserves have particular conservation significance. The concentration on sites away from urban areas is similar to that described by Scott and Sullivan (2000) in Southern California where discounting (writing off) of the biological values of the urban rural fringe has led to the mismanagement of remnant vegetation and wildlife habitat and inappropriate landscape planning outcomes.

Recent developments in the field of conservation planning and reserve design have emphasised the need to conserve areas based on their "irreplaceability" (the contribution that a site will make to the reserve network) and vulnerability (the likelihood of an area being destroyed or degraded) (Faith and Walker, 1996; Pressey et al., 1996; Pressey and Taffs, 2001). Because of the very small amount of native grassland remaining in Melbourne, it is likley that all sites supporting native grassland in the region are irreplaceable and of great conservation value for any reserve system. Consequently, the results of our models could be used to develop a comprehensive conservation plan for Melbourne's grasslands where sites of high biological significance that are at high risk of impending of development or degradation are prioritised for purchase or management actions. For example based on our results, good quality grassland close to any planned freeways should be targeted for purchase or protection using planning controls, while weed control should be a priority along railway easements supporting native grassland. Our results indicate that previous government attempts to preserve native grasslands in Melbourne have largely failed and a new, more strategic approach is warranted.

4.4. Future trends

The destruction of native grasslands by development and degradation through weed invasion is a continuing process. This research reflects the status and extent of Melbourne's grasslands as of October 2000. However as we prepared this manuscript for publication, approvals had been granted for industrial and housing developments that will destroy a further 381 ha of native grassland. The sites to be developed are some of the largest patches of native grassland remaining in the Melbourne area and support many threatened species (Department of Conservation and Environment, 1990). The ultimate development of these sites will reduce the area of native grassland in Melbourne by a further 9.4% to 3690 ha.

The remaining grasslands will continue to be threatened by weed invasion and other degradation processes. Many highly invasive alien species, particularly introduced stipoid grasses such as *Nassella neesiana*, currently threaten Victorian native grasslands (Carr et al., 1992; McLaren et al., 1998; Morgan, 1998). Although weed control techniques are being developed (Lunt and Morgan, 2000; Campbell et al., 2002), due to the lack of active management at many grassland remnants, particularly railway reserves, it seems many sites will continue to degrade in the future.

It is hoped that this research will lead to the development of a strategy based on prioritising sites based on biological significance and the likelihood of destruction and degradation leading to preservation and effective management of urban grasslands. A greater understanding of the landscape and societal drivers of native grassland destruction and degradation can be obtained through the use of models such as ours and should assist conservation planners. This approach can help to identify patches vulnerable to future development and degradation and enable prioritisation of preservation efforts based on the level of significance balanced with the level of impending threat. It can also identify the consequences of major infrastructure projects on natural areas, and landscape pattern, and help to understand them as a driver of land-use change.

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