Landscape legacies: Koala habitat change in Noosa Shire, South-east Queensland

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ABSTRACT

Present day Australian landscapes are legacies of our colonial history, while future landscapes will be legacies of ecological processes and human impacts occurring today. This paper investigates the legacies of European settlement of Noosa Shire, South-east Queensland, with particular emphasis on the economic and political drivers and the resultant loss and fragmentation of Koala *Phascolarctos cinereus* habitat. Patterns of habitat loss between 1860 and 1970 were quantified at a coarse level from historical and land tenure records, while changes over the past 30 years were mapped at a finer spatial resolution from aerial photography and satellite imagery. Periods of high economic growth and to lesser extents depression are linked to increased vegetation clearing. Fifty per cent of *P. cinereus* habitat has been lost since 1860, with habitat class 2A (30-<50 per cent of preferred habitat trees) and 2C (10-<30 per cent of preferred habitat trees) suffering the highest proportion of loss. The period of greatest habitat loss was between 1890 and 1910, linked to the development of the dairy industry in the western half of Noosa Shire. A second significant phase of loss occurred since 1970, linked to the planting of exotic pine plantations, urbanisation and rural subdivision, with 35 per cent of remaining habitat being cleared, mainly in the southern part of the Shire. The cumulative loss of habitat has been accompanied by increasing levels of habitat fragmentation indicated by reduced patch size and increased patch linearity. Further analysis of the temporal aspects of habitat change is required in order to test the hypothesis that there is a relaxation period between the timing of habitat loss and current pattern of habitat occupancy of *P. cinereus* populations.

Key words: *Phascolarctos cinereus,* habitat loss, ecological history, landscape legacies, human settlement, Noosa Shire, South-east Queensland

Introduction

An understanding of landscapes and their dynamics is essential for conserving and restoring fauna populations living in fragmented Australian landscapes (Saunders *et al.* 1991). Landscapes are contextual phenomena that possess both spatial and temporal components (Marucci 2000). However, while the importance of the spatial dimensions is increasingly recognised in fauna conservation efforts, the temporal component is often overlooked. This is despite the recognition of a time lag or relaxation period between habitat reduction and population decline (Tilman *et al.* 1994; Saunders *et al.* 1991; Hanski 1998; McAlpine *et al.* 2002). Present day landscapes result from previous environmental conditions and human impacts, and it follows that landscapes of the future will be legacies of ecological processes and human impacts occurring today. As a legacy, each landscape has a unique story or landscape biography, which explains the temporal context of the current landscape (Marucci 2000). This includes both its biogeographical development and human actions which modify landscape structure and function. Ecological history helps us to fill the temporal gap by considering the past interactions of people with their environments. A range of techniques is used, some spatially accurate and precise, whereas others are subjective interpretations or 'stories', in which changing cultural perceptions play an important part (Bowman 2002). Together, they provide a valuable source of information when formulating future land management decisions (Dovers 2000; Bowman 2002).

Many present day Australian landscapes are a legacy of European settlement, when native ecosystems were rapidly cleared for agriculture and grazing with no consideration of their ecological values (e.g. Hobbs and Hopkins 1990; Knott *et al.* 1998). In southern Queensland, fertile coastal landscapes were the first to be transformed as they were easily accessible and contained valuable timber such as *Toona ciliata* (Red Cedar) and *Araucaria* spp. (Hoop and Bunya Pine) (Powell 1998; Brown 2000). Settlers often followed in the wake of timber getters, using logging tracks and rivers to access land along river valleys. The first settlers of inland landscapes in southern Queensland were pastoralists, moving north through the Hunter Valley and the New England tablelands to claim the woody grasslands of the Darling Downs and the alluvial floodplains of the Condamine, Macintyre, Maranoa Rivers and their major tributaries.

The Koala *Phascolarctos cinereus* is one of many South-east Queensland fauna species that has declined as a legacy of the historical clearing of their preferred eucalypt forests and woodlands (Lunney and Leary 1988; Pahl 1996; Melzer and Houston 2001). This decline is typical of the steady reductions in *P. cinereus* populations across their natural range as a result of habitat loss and fragmentation (e.g. Lunney and Leary 1988; Knott *et al.* 1998). Understanding how much habitat was lost, where it was lost, and at what rate provides a valuable historical perspective for understanding the current distribution and abundance of *P. cinereus*, and planning future landscapes for both human communities and habitat conservation and restoration (Lunney *et al.* 2000). Although *P. cinereus* utilises a range of trees for both food and shelter, it generally favours a few species such as *Eucalyptus tereticornis* (Queensland Blue Gum), *E. robusta* (Swamp Mahogany), *E. microcorys* (Tallow Wood) and *E. bancroftii* (Bancroft's Red Gum) (Gordon *et al.* 1990; Hasegawa 1995; Phillips and Callaghan 2000). Variations in tree species used for food within a region relate to the composition of vegetation communities within a home range, gender and season (Hindell and Lee 1987; White 1999).

This paper quantifies *P. cinereus* habitat change and underlying social, economic and political drivers for Noosa Shire (South-east Queensland) since European settlement began in 1860. The focus is on habitat loss and fragmentation as these are considered the greatest threat to the long-term survival of wild *P. cinereus* populations (Pahl *et al.* 1990; Lunney *et al.* 1997, 2000). Other historical factors, such as hunting are considered, although in less detail. The data used for this study are commonly associated with quantifying landscape change, namely aerial photographs, digital satellite imagery, and historical maps and records (Dunn *et al.* 1990; Mast *et al.* 1997; Turner *et al.* 2001).

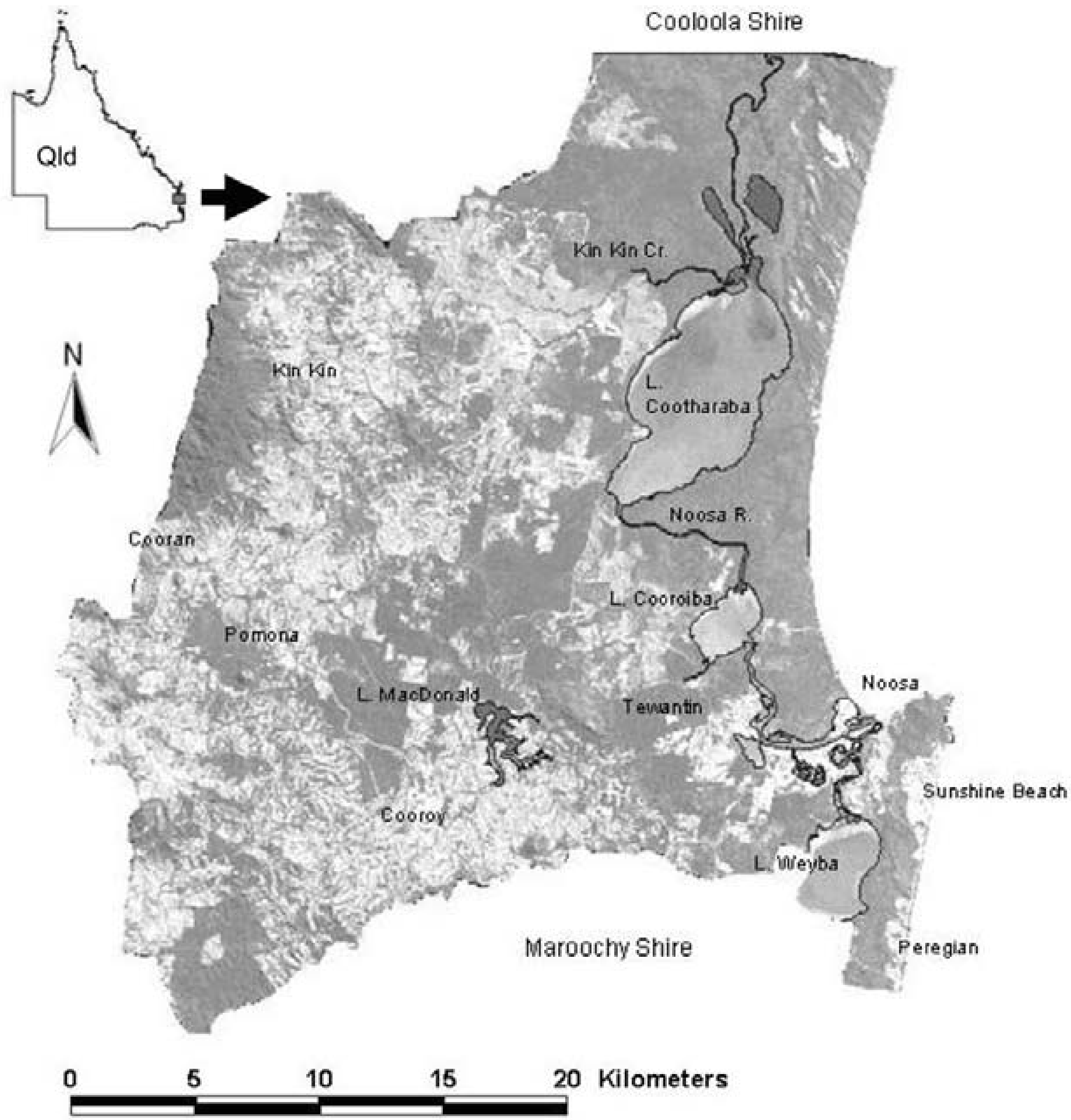

Figure 1. Main features of Noosa Shire. The background is Band 2 (green) of the Landsat Thematic Mapper image captured in 1997. The pale areas are non forest while the darker areas are forest.

Methods

Study area

Noosa Shire (86,823 ha) is located within the South-east Queensland biogeographical region (Figure 1). The coastal portion of the Shire is formed by Pleistocene sand deposits overlaid in places by alluvial deposits, with a chain of brackish lakes including Lakes Cootharaba, Cooroiba and Weyba. The lake system is linked by the Noosa River, which flows south from the Cooloola sandmass to enter the sea just north of Noosa Heads (Thompson 1975). Vegetation of the coastal region includes heathland and sedgeland communities, *Melaleuca quinqernervia* (Swamp Paperbark) forests, low open to tall closed eucalyptus forests of *E. tereticornis*, *E. bancroftii*, *E. robusta, E. racemosa* (Scribbly Gum) and patches of sub-tropical rainforests. West of these lakes, a sandstone escarpment rises to approximately 250 m, incised by tributaries of the Noosa River such as Kin Kin and Cooloothin Creeks. The escarpment is predominantly vegetated by open eucalypt forests with species such as *E. pilularis* (Blackbutt), *E. racemosa*, *E. siderophloia* (Grey Ironbark), *Corymbia gummifera* (Red Bloodwood), *C. intermedia* (Pink Bloodwood) and *C. trachyphloia* (Brown Bloodwood).

The elevated area to the west of the escarpment is shaped by diverse geological formations ranging from granite intrusions and volcanic outcrops to sandstone conglomerates. Native vegetation of this area is equally diverse, ranging from sub-tropical rainforests on the granite intrusions and volcanic soils to dry eucalypt forests dominated by *E. tereticornis*, *E. siderophloia, C. intermedia* and *C. citriodora* subsp. *variegata* (Spotted Gum) on the alluvial and sandstone soils. The south-west of the Shire forms part of the Mary River catchment, and consists of hilly terrain with a shale substrate with *E. siderophloia, C. intermedia and C. citriodora* subsp. *variegata* the dominant overstorey tree species.

Prior to European settlement, Aboriginal people were the custodians of this rich diversity of native ecosystems. European settlement began in 1860, with present day land use varying from agriculture and grazing in the west, to a concentration of urban and tourism in the south-east centred on the townships of Tewantin and Noosa Heads, with the Cooloola and Noosa River National Parks in the north. Noosa Shire supports a low-medium density population of *P. cinereus*, which is found primarily in the southern half of the Shire and west of Lake Cootharaba (M. Bowen, unpublished data).

Quantifying *P. cinereus* habitat change

A three-stage study method was adopted in order to quantify changes to *P. cinereus* habitat since European settlement. First, details of land settlement history were obtained using historic records, Parliamentary papers and various pieces of State Government legislation as the primary data sources, supported by a published economic history of Noosa Shire (Edwards 1998, 2001).

Second, land use for 1894, 1910, 1970, 1988 and 1999 was mapped using ArcView 3.3 GIS (ESRI 2002) to identify changes in native vegetation cover for each time step. Data sources included: two land survey maps of Wide Bay (1894 and 1910); black and white aerial photographs (1970); and Landsat Thematic Mapper (Landsat TM) images (1988 and 1997). Changes in habitat between 1997 and 1999 were minimal, and an assumption was made that areal changes in land use would also be minor for this period. Therefore, the date for the final time step is referred to as 1999 from here on. Five land cover classes were identified: water bodies, native forest, farmland (including non-native forest), urban development and land that had been recently cleared, mostly in the felling cycle of exotic pine plantations or undergoing urban development. These were subsequently grouped into: native forest, non-native forest and water. The aerial photographs and Landsat TM images did not cover a small area of native forest in the far north of the Shire and this is shown as a further class in Figure 2, labelled "Not included". For the 1894 and 1910 land survey maps, no data were available on the amount of remnant vegetation remaining on recently converted farmland, and only areas of State Forest, timber reserve and unallocated land were classed as forest, and thus *P. cinereus* habitat. Historical evidence shows that the majority of vegetation on farms was cleared soon after settlement and an assumption was made that little habitat would remain in these areas (e.g. Bolton 1981; Lunney and Leary 1988; Bonyhady 2000).

Finally, the native forest land cover categories were reclassified into four *P. cinereus* habitat classes in accordance with the Koala Habitat Atlas prepared for Noosa Shire Council by the Australian Koala Foundation (Callaghan *et al.* 2000). Field surveys and analysis of 4,000 trees were used to determine *Eucalyptus* spp. preferred by *P. cinereus* within Noosa Shire as a basis for compiling the Habitat Atlas (Callaghan *et al.* in prep.). Tree species were grouped into three classes: primary, secondary and supplementary according to Callaghan *et al.* (2000), Phillips *et al.* (2000), and Philips and Callaghan (2000). A primary koala food tree is a *Eucalyptus* spp. that records a significantly higher proportion of faecal pellets compared to other *Eucalyptus* spp., while a secondary food tree is a *Eucalyptus* spp. that records a significantly higher proportion of faecal pellets compared to that observed for remaining *Eucalyptus* spp. (excluding the primary category). A third category, supplementary food tree, is a species of *Eucalyptus* that records a significantly lower proportion of faecal pellets than for a secondary species, but greater than for other tree species generally lacking evidence of active selection by *P. cinereus*.

Habitat classes used in this study (Table 1) were based on the proportions of primary and secondary tree species as described above matched with the proportional abundances of the same tree species derived from community descriptions of vegetation units mapped by the Queensland Herbarium, as part of their regional ecosystem mapping program (Queensland Herbarium 1998). Non-native exotic pine plantations and rainforest were classed as non-habitat, while some heathland communities were classified as habitat class 2C on the basis of occasional presence of food trees such as *E. robusta* and *E. bancroftii*. Such communities also may be utilised by *P. cinereus* for movement and shelter between areas of more important habitat. Two digital data sets for Noosa Shire were supplied by the Queensland Herbarium: pre-clearing and remnant native vegetation in 1999. The pre-clearing data set was taken to represent vegetation communities existing in 1860, prior to European settlement.

Table 1. *P. cinereus* habitat classes and major tree species. Note, two additional *Eucalyptus* species are ranked as supplementary food trees, *E. grandis* and *E. acmenoides*. *P. cinereus* also is known to use mainly non-eucalyptus species for supplementary food and shelter in Noosa Shire including *Callitris columellaris, Acacia aulacocarpa, A. melanoxylon, Melaleuca quinquenervia, Lophostemon suaveolens, L. confertus, Allocasuarina torulosa, Corymbia intermedia* and *Banksia serrata* (Callaghan *et al.* 2000).

Habitat Class	Major Tree Species	% of Overstorey Koala Food Tree Species
Primary	*E. bancroftii,* *E. microcorys,* *E. robusta,* *E. tereticornis.*	Primary food trees >50%
2A	*E. propinqua,* *E. resinifera,* *E. siderophloia.*	Primary food trees 30-50%; or Primary plus Secondary food trees >50%; or Secondary food trees >50%
2B	As for 2A	Primary food trees <30%; or Primary plus Secondary food trees 30-50%; or Secondary food trees 30-50%
2C	As for 2A	Secondary food trees <30% Primary food species absent or <10%
Non-habitat		Non-native forest, rainforest, some heathlands, reed swamps, mangroves and cleared land.

Changes in the area and spatial configuration of each habitat class plus all habitat classes combined were quantified using selected landscape metrics (Table 2). Landscape fragmentation analysis was performed for the pre-clearing (1860) and remnant (1999) Queensland Herbarium data sets as landscape metrics are sensitive to differences in land cover mapping techniques (Simpson *et al.* 2002; Farina 2000). For the purpose of this study, the two most important components were the area of each *P. cinereus* habitat class lost and the level of spatial fragmentation of individual habitat classes plus all habitats combined.

Results

Settlement history of Noosa Shire

There is a relationship between loss of *P. cinereus* habitat and the different phases of European settlement of Noosa Shire. Broadly, there were three principal phases of settlement, occurring in different areas, and associated with different economic activities. These phases are briefly outlined below, while the corresponding changes in land cover are shown in Figure 2. Appendix 1 shows a detailed timeline of land settlement history in Noosa Shire.

Table 2. Landscape metrics used to measure Koala habitat change (1860-1999) (Source: McGarigal *et al.* 2002 and Simpson *et al.* 2002).

Landscape metric	Purpose of measurement	Limitations
Number of patches	Measure of landscape configuration and thus fragmentation (also basis for other metrics)	Not spatially explicit.
Mean patch size	Mean patch size (ha) of each habitat class in the landscape as a proportion of number of class patches and total class area	Measure of average patch size. Needs to be considered with other metrics such as class area, number of patches and patch size standard deviation.
Patch size standard deviation	Measures absolute variation (ha) as function of mean patch size range of patch sizes so indicates the level of variability across patches	Can be difficult to interpret unless used in conjunction with mean patch size.
Perimeter: area ratio	Simple measurement of patch shape, using the average ratio of patch perimeter length (m) and patch area (ha)	Varies with size of patch, even if shape remains the same.

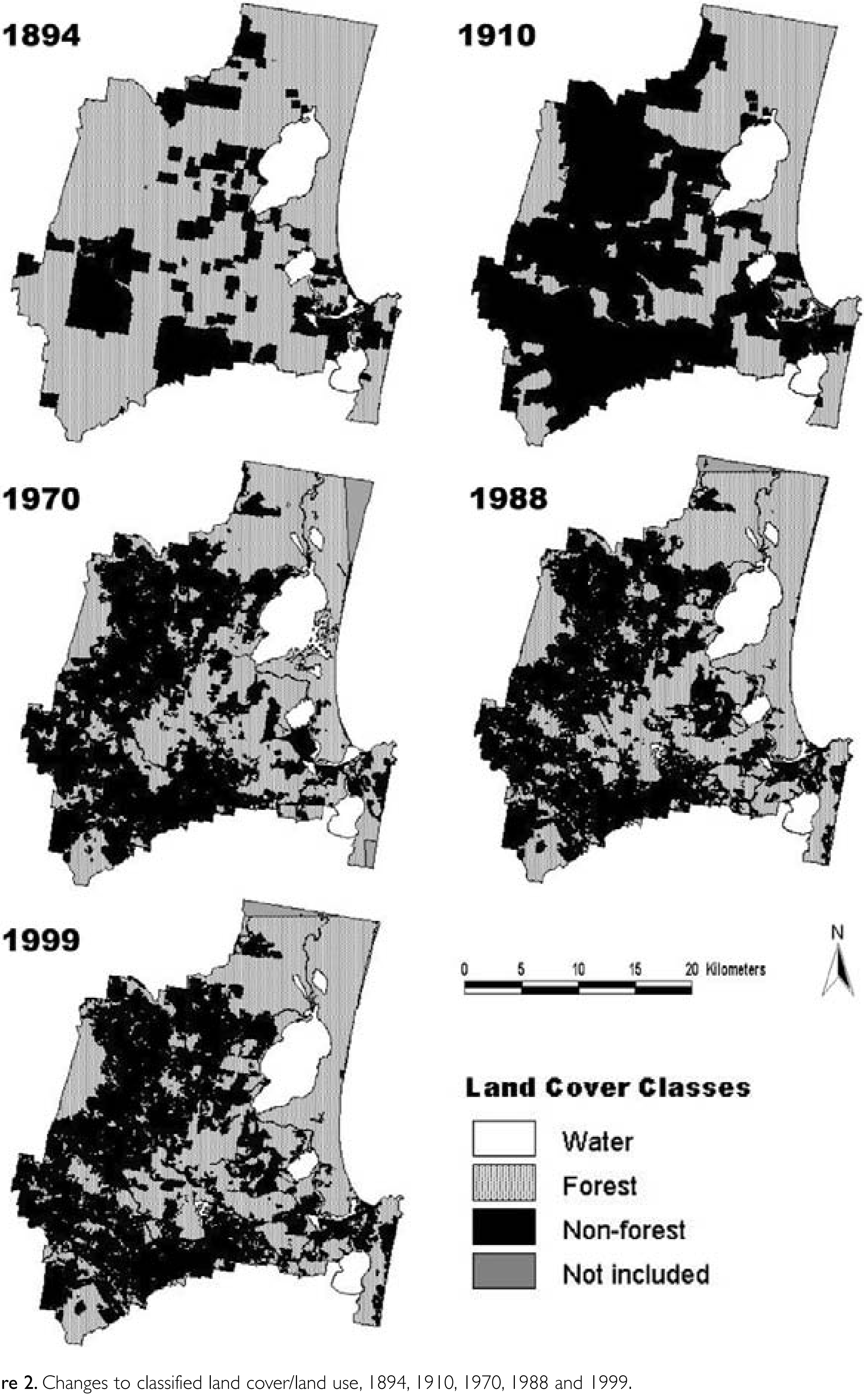

Figure 2. Changes to classified land cover/land use, 1894, 1910, 1970, 1988 and 1999.

Early Settlement and Timber Getting, 1860-1890

Land settlement in Noosa Shire began in the early 1860s with timber getting in the thick coastal forests (which had previously deterred pastoral settlers). As supplies of Red Cedar in the Brisbane Valley became scarce, timber getters moved north in search of new sources (Brown 2000). The locations of areas harvested were largely governed by ease of access to timber and the transportation of sawlogs, and were primarily close to waterways (Powell 1998). New sources of timber were sought by explorers such as Cunningham and Oxley, as it formed an important resource for export to Britain (Powell 1998). Pockets of rainforest along the creeks and on volcanic soils of Noosa Shire proved a valuable source of Red Cedar, *Agathis robusta* (Kauri Pine) and Hoop Pine (Figure 3). Timber getting was carried out by companies such as Luya, McGhie, Goodchap and Woodburn, who established a sawmill and settlement at Elanda Point and leased forests on the north-west shores of Lake Cootharaba; and Dath Henderson, whose cutting lease was in the Cooroy area. Some idea of the importance of the timber trade in the early years of settlement in Noosa can be gleaned from the fact that three million linear feet of timber were shipped to Brisbane annually in the 1870s (Edwards 2001).

Settlers followed in the wake of the timber getters, using logging tracks to access land (Brown 2000), and many settlers were employed in the timber trade to provide an income while they cleared their properties and planted crops. During the 1870s, a number of farms were established along the western shore of Lake Cootharaba and the main creeks in the Shire. Early settlers practised mixed farming, combining subsistence products with cash crops. Sugar cane was one of the first cash crops grown on farms along the western shore of Lake Cootharaba and in the Cooroy district (Edwards 2001).

During this period, the Queensland Government actively promoted closer land settlement through various Land Acts, both for ideological reasons and also to raise revenues to repay a loan of £10,000,000 to the British Government (Edwards 2001). Land settlement schemes were often unsuccessful for a variety of reasons, including unsuitability of land for agriculture, small farm sizes, lack of farming experience, and insufficient farm income. By 1890, however, nearly 20,000 ha of land had been released for farming (Figure 2). An increasing scarcity of timber as a result of indiscriminate land clearance resulted in the reservation of large areas of unused Crown Land as timber reserves (Powell 1998). This was of some importance to Noosa Shire, as significant tracts of land were set aside as timber reserves.

Figure 3. Fallen *Agathis robusta* (Kauri Pine) at Sister Tree Creek, Kin Kin, 1917, showing the impressive size of some old growth trees (Source: Tutt 1977).

Closer Settlement and Dairy Farming, 1890-1960

The Queensland Government continued to pursue closer settlement as the way to increase rural populations and relieve urban poverty, but progress was variable due to both economic and environmental factors (Figure 4a). The early 1890s were marked by an economic downturn, culminating in the depression of 1893. A series of severe floods in the early 1890s forced many settlers off the land (Page 1970). Noosa was affected also by the completion of the railway between Gympie and Yandina in 1891 which deprived Tewantin of its role as a port for the Gympie gold fields and the closure of the sawmill at Elanda Point in 1892 after a boiler explosion (Edwards 2001). The technological improvements in butter production in the 1890s and high export profits made the dairy industry ideal for supporting closer settlement in south-east Queensland (Camm 1971). When the economy revived in 1894, there was a renewed demand for dairy land around the Cootharaba, Pomona, Cooroy and Tewantin areas, with settlers taking up abandoned properties and newly released land. Environmental conditions again influenced the viability of settlement, with a prolonged drought lasting from the late 1890s to 1903 (Brown 2000; Office of Economic and Statistical Research 2002).

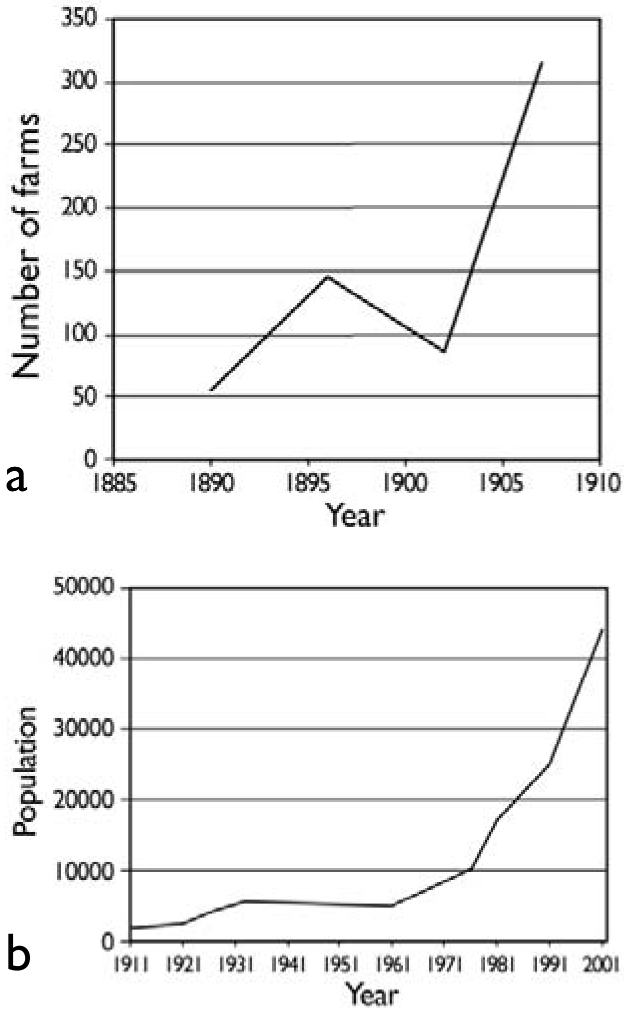

Figure 4. (a) Number of farms in Noosa Shire, 1890 to 1907; and (b) Population growth in Noosa Shire, 1911 to 2001.

When the drought ended in mid-1903, there was another wave of interest in land selection (Pedley 1979). Over the next seven years, nearly 10,000 ha of land in the west and south of the Shire were released for settlement; mostly from former timber reserves (Figure 2). Clearance of vegetation seems to have proceeded rapidly on these farms (Figure 5). The Risley Group from the Richmond River, northern New South Wales, which took up land near Cooran, was credited with "the first really systematic falling of the scrub … undertaken by men who understood the technique of putting scrub land under grass for dairying purposes" (Page 1970). In the meantime, farmers continued to use timber as a source of income while establishing their farms and the timber industry remained an important component of Noosa's economic base. In 1905 the *Gympie Times* stated that in the Cooran-Pomona area "the very large majority of settlers are engaged in the timber industry, either cutting and hauling logs for bridge timber to the railway, pine to Cootharaba Lake or chopping sleepers" (quoted in Edwards 2001 p.34). A tourism industry started to develop after the 1920s with improvements to roads and bridges allowing easy access to Noosa Heads (Cato 1989). The rise in population due to dairy farming provided the impetus for Noosa Shire to be declared in 1910. Population growth continued through the 1920s and 1930s was followed by stability from 1940 to 1960 (Figure 4b).

Urban development and tourism, 1960-present

By the 1960s, the viability of many family-run dairy farms changed due to the decline of export markets to Britain and the changing social and economic expectations of younger generations (Drane and Edwards 1962). Thus both social and economic factors propelled a population flow from rural farms to urban centres. Increased mobility and higher incomes meant that resort tourism increased in popularity and Noosa was well positioned to take advantage of it. Some dairy farms were converted to beef production and some were sub-divided for rural residential and urban expansion around Cooroy and Pomona. Coastal settlements, such as Noosa Heads, Tewantin and Sunshine Beach expanded rapidly. Much of the impetus for urban development came from the activities of T.M. Burke Pty Ltd (Edwards 2001). This company foresaw an increasing demand for coastal housing, and was responsible for developing the Sunshine and Peregian Beach estates south of Noosa Heads. Development also occurred at Hays Island and Hastings Street in Noosa in the 1970s and the Noosa Waters canal estate in the late 1980s (Cato 1989; Edwards 2001). This period was also marked by increasing environmental activism, following global trends. The Noosa Parks Development Association was founded in 1962, and was largely responsible for preventing mining of the Coloured Sands at Teewah, north of the mouth of the Noosa River during the mid 1960s, and the eventual gazetting of Cooloola National Park in 1975. The Park comprises 23,030 ha, plus a Faunal Reserve of 4,322 ha and straddles Noosa and Cooloola Coast Shire to the north (Edwards 2001). A strip of land along the eastern shores of Lake Weyba was protected in 1977 (Cato 1989). The Association was largely responsible for the enlargement of Noosa National Park at Noosa Heads to 350 ha by successfully protesting against the construction of a coastal esplanade (Edwards 2001).

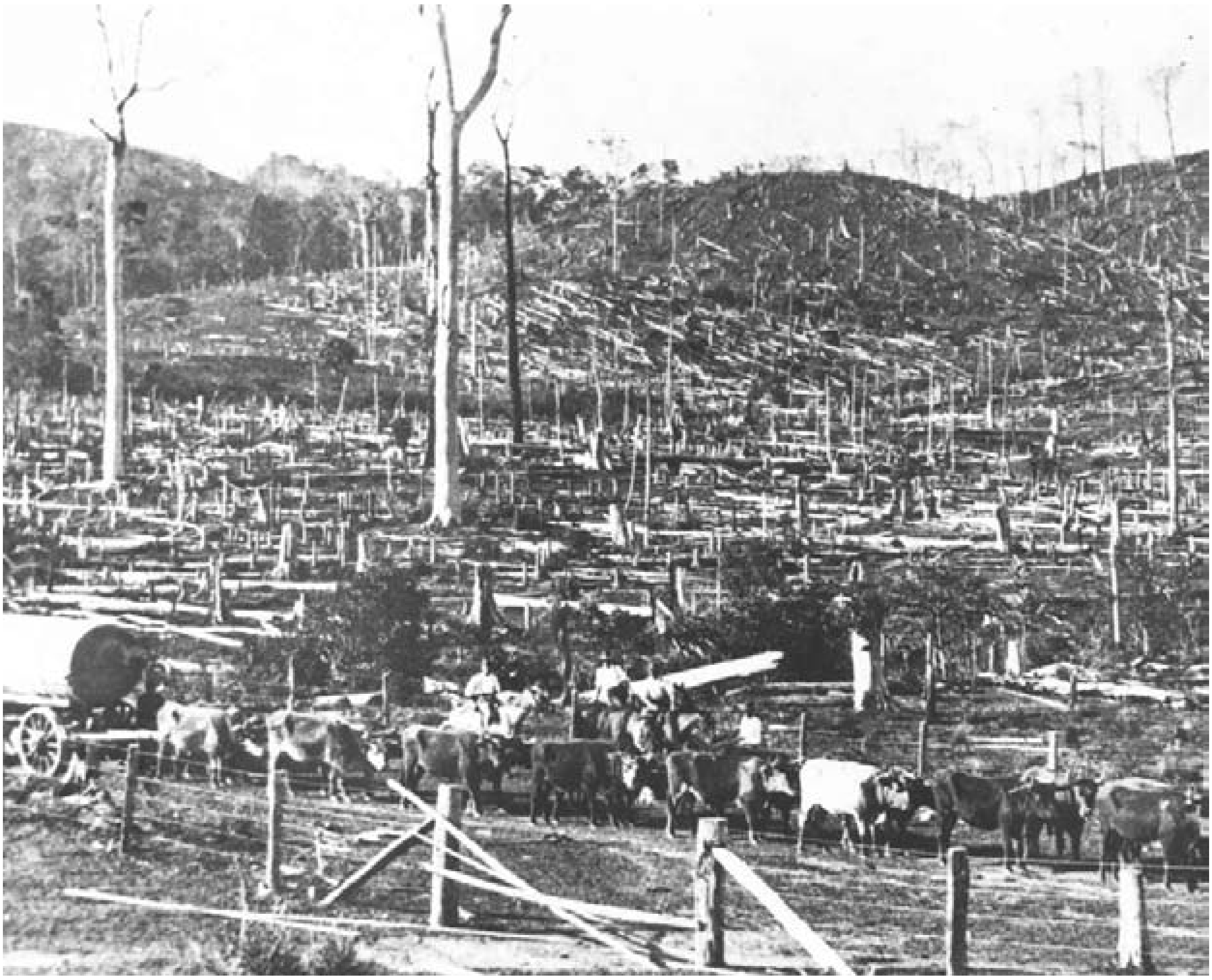

Figure 5. Undated photograph of land clearance by clear felling and ringbarking near Pomona. Land clearance was generally carried out soo n after settlement. Likely dates would be in the range of 1870-1890. (Source: Waterson and French 1987)

Loss of *P. cinereus* habitat

Figure 6 shows the change in the total estimated area of each *P. cinereus* habitat class for the selected mapping dates (Table 1). The area of *P. cinereus* habitat decreased rapidly from 1860 to 1910, followed by a gradual increase to 1970. The most extensive habitat classes, 2A and 2C, showed the greatest decline. Between 1970 and 1999 the area of habitat again decreased, particularly in Class 2A and 2B. Over the whole period, Class 2B went from having the second lowest area to having the highest area. Primary habitat continued to have the smallest total area but experienced the lowest overall change. Figure 7 shows a series of thematic maps of classified *P. cinereus* habitat at each of the specified mapping dates.

In 1860, prior to European settlement, suitable *P. cinereus* habitat covered 89 per cent of the land area of Noosa Shire. Primary habitat covered 10 per cent of the total land area, and occurred primarily on the alluvial flood plains west of Lake Cootharaba, with additional patches along the lower Noosa River and Weyba Creek. Class 2A habitat covered 24 per cent of the Shire and was found along the eastern catchment of the Mary River, the middle and upper valley of Kin Kin Creek, and in the extreme south west of the Shire. Class 2B habitat covered 19 per cent of the land area, and was found in smaller scattered patches. Larger areas of 2B habitat occurred in the north and south of the Shire, with linear patches in the west. Habitat class 2C covered 35 per cent of Noosa Shire, and occurred mainly in two large patches occupying the higher ridges of the south-west of the Shire and upper Kin Kin Creek areas. Other vegetation and sand dunes covered the remaining 12 per cent of the Shire, and occurred mainly in the coastal dune system.

By 1894, farms were scattered through the central zone of Noosa, west of Lake Cootharaba, with further centres around the towns of Pomona, Cooroy, Kin Kin and the lower Noosa River. By 1910 much of the central and western parts of Noosa had been given over to farming, but the coastal strip south of Noosa Heads had been abandoned. A noticeable feature of the maps is the lack of change on the lands to the north and east of Lake Cootharaba (Figure 1). Between 1970 and 1999, the main changes to habitat occurred in the south-east quadrant of the Shire. These changes resulted from an increased area being given over to pine plantations and an increase in sub-divided land, both around existing towns and as rural residential subdivisions.

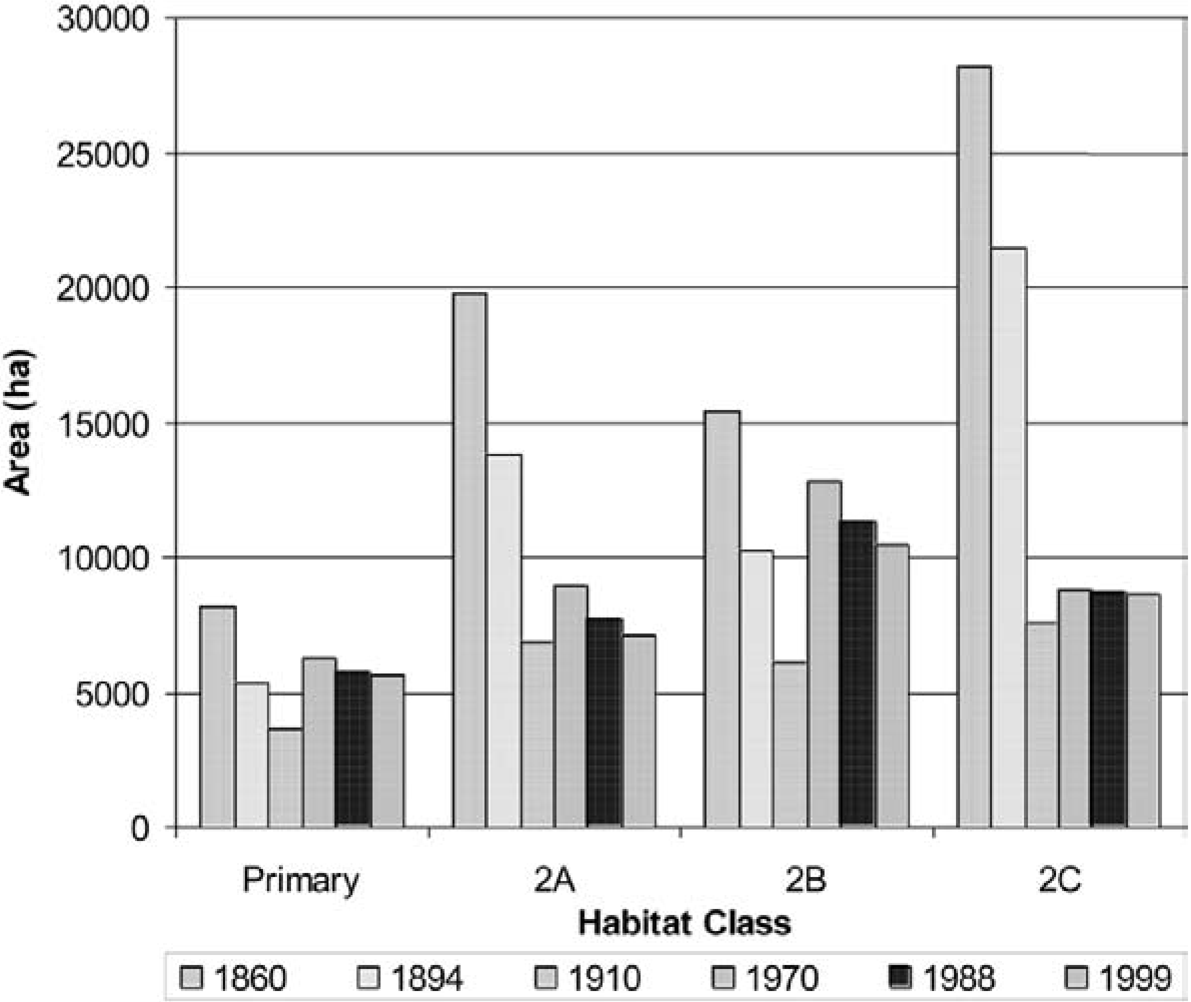

Figure 6. Total area of classified *P. cinereus* habitat for respective mapping dates. The totals for 1894 and 1910 represent the minimum habitat that existed at these dates and do not include remnant habitat on farmland.

Landscape analysis

Figure 8 graphs the landscape pattern metrics that were applied to the four *P. cinereus* habitat classes plus all habitats combined for the dates 1860 and 1999. All classes showed increased number of patches, the prime measure of fragmentation, between 1860 and 1999, with the greatest changes occurring in Classes 2A and 2C and all classes combined which increased from 74 to 490 patches. It is interesting to note, however, that the smallest relative increase was in Class 2C, which suffered the greatest loss of area (Figure 6). Class 2A showed the greatest reduction in mean patch size of individual classes, decreasing from 194 ha in 1860 to 20 ha in 1999. However, there was an even more dramatic reduction in the mean patch size of all habitats combined, declining from 966 ha to 63 ha for the same period. The patch size standard deviation, which is a measure of landscape heterogeneity, shows a similar result with a major reduction in the variation of patch sizes, while the mean perimeter-area ratio shows a general increase across all habitat types, indicating an increase in the amount of edge habitat. Class 2C showed the largest increase, originally occurring as large unbroken areas in 1860, but becoming highly fragmented by 1999. Overall, the landscape metrics illustrate a transition from a continuous mosaic of *P. cinereus* habitat of varying quality in 1860 to a highly fragmented landscape in 1999, dominated by a few large habitat patches with a major decrease in mean patch size for the individual habitat classes plus all habitats combined.

Discussion

Present day landscapes of Noosa Shire are a legacy of European settlement and natural resource use dating back to 1860. The total amount of *P. cinereus* habitat has halved in the past 140 years. However, the patterns of habitat loss have occurred unevenly, both spatially and temporally in terms of phases of European settlement, resulting in differences in the relative proportion of *P. cinereus* habitat categories lost. The majority of habitat loss occurred between about 1890 and 1910, when dairy farming expanded rapidly as a major export industry (Camm 1971). This pattern of rapid clearance is similar to other areas of eastern Australia, although the timing varies. For example, in the Bega Valley, Lunney and Leary (1988) stated that the main period of clearance was from the mid-1860s to the 1870s, also related to the dairy industry. Habitat loss at this time was driven by economic, policy and cultural factors. In economic terms, Queensland was in need of income, in part generated through the sale/lease of land and the primary production carried out on that land. The need for income applied also to individual settlers who could

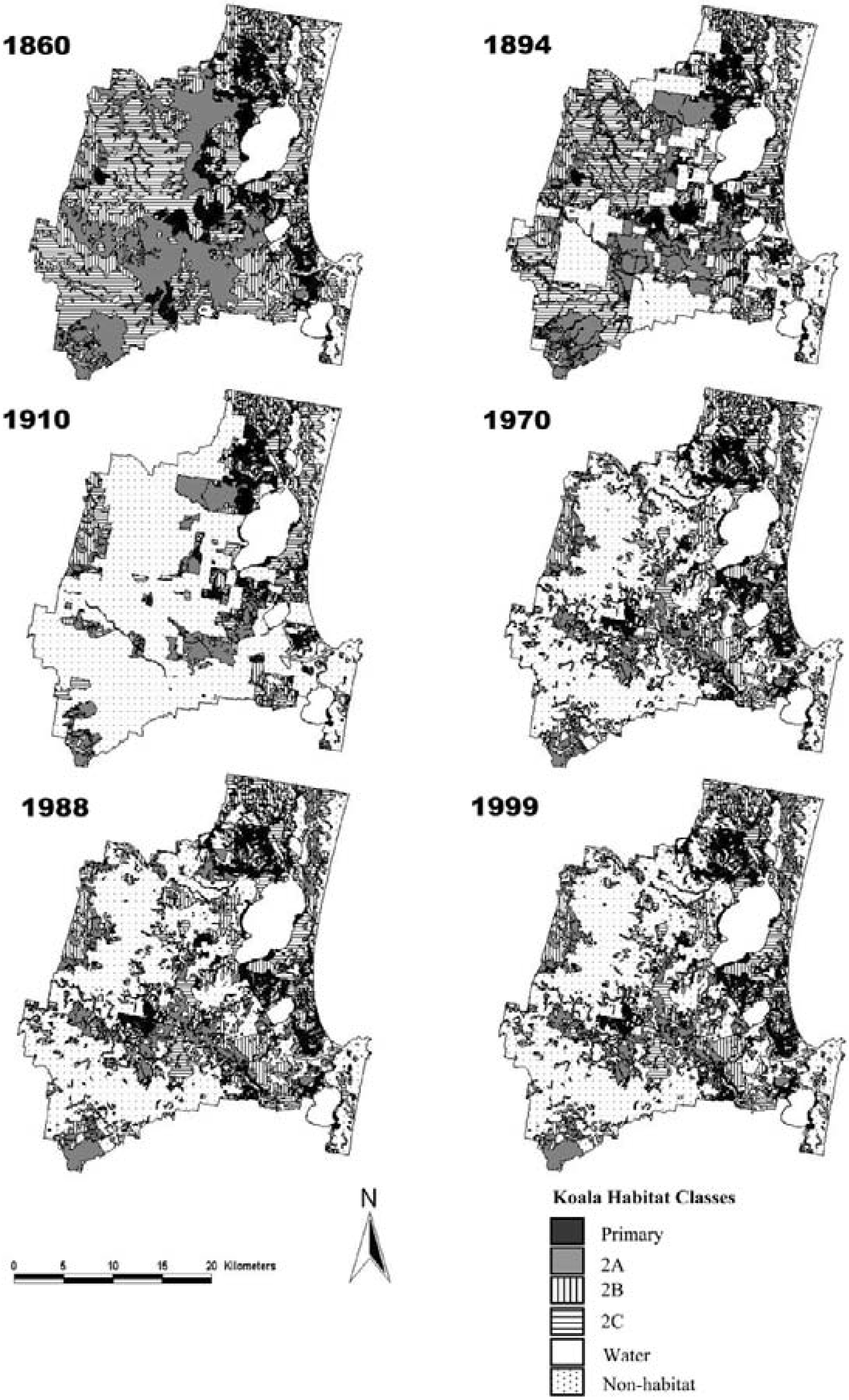

Figure 7. Thematic maps of *P. cinereus* habitat in 1860, 1894, 1910, 1970, 1988 and 1997. Habitat was assumed to exist only within the forest class on the land use maps (Figure 2).

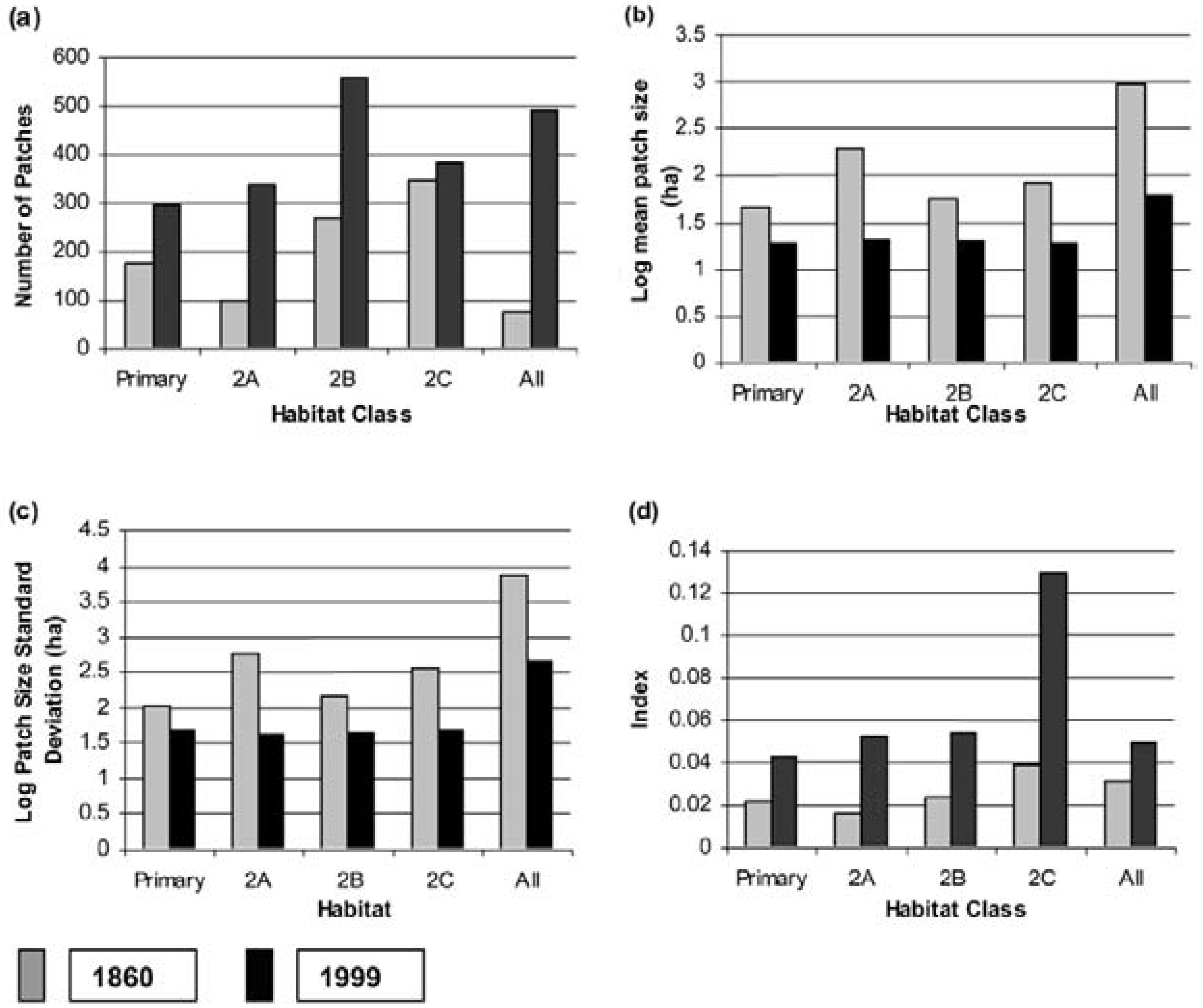

Figure 8. Selected landscape pattern metrics for habitat classes on classified *P. cinereus* habitat maps, 1860 and 1999: (a) Number of patches; (b) Mean patch size; (c) Patch size standard deviation; and (d) Mean perimeter-area ratio.

not earn their living from farms until the land was cleared for crops and livestock. Politically, the State government favoured closer settlement over large pastoral runs, and legislation was geared to achieve this end (Kingston 1965). Culturally, many of the settlers were migrants from Europe who sought to transform an alien forested landscape into a familiar agricultural one (Bolton 1981; Hobbs and Hopkins 1990; Bonyhady 2000).

A second major phase of habitat loss since 1970 is due in part to the replacement of native forest with pine plantations in two areas west and south-west of Lake Cootharaba, and also to the large increase in urbanisation and rural residential sub-division. Worth (1996) estimated that half the remaining *P. cinereus* habitat on the Tilligerry Peninsula (Port Stephens, NSW) was lost to urban development and sand mining between 1954 and 1992. Thus, there appears to be a link between the development of new economic bases (dairying and urban population growth) and increased rates of habitat change.

The loss of *P. cinereus* habitat has been accompanied by increased fragmentation of remaining habitat (Figure 8). In 1999, the percentage of habitat remaining in each class was: Primary 70 per cent, 2A 35 per cent, 2B 67 per cent and 2C 31 per cent. Areas of remaining habitat have some level of connectivity, via riparian corridors and scattered trees. White (1999) found *P. cinereus* did utilise scattered trees in a rural setting, however, Gordon *et al.* (1988) emphasise that the spatial positioning of habitat was critical to its use at Springsure, Central Queensland. Habitat utilisation surveys of faecal pellet distributions indicate that in 2002 *P. cinereus* occurred mainly in the southern third of the Shire (AKF unpublished data, M. Bowen unpublished data). This seems to reflect their historic distribution (Brown 2000), but both Jurskis (2001) and Norton and Neave (1996) point out the difficulty of establishing past habitat utilisation by *P. cinereus* based on present day habitat occurrence. The relatively undisturbed habitat in the north-eastern part of Noosa, east of the Noosa River, does not appear to support a significant *P. cinereus* population, possibly due to lower soil fertility. For example, Cork and Braithwaite (1996) found that a difference in the ratio of nutrients to carbon-based anti-nutrients explained the distribution of arboreal marsupials, while Thompson (1975) states that the podsolic soils in this area are low in nutrients. Therefore, the presence of suitable vegetation communities alone does not always indicate the level of habitat utilisation by *P. cinereus*.

Consequences for *P. cinereus*

By 1890, approximately 20,000 ha had been released for settlement. Settlement schemes were often unsuccessful in the long-term, and environmental constraints forced farmers to abandon their land in many instances. Clearance of native vegetation on farms was driven by both economic and regulatory necessity as well as cultural desirability. The necessity came from the need to free space for crop growing. Culturally, the prevailing attitude during this period of settlement was that undeveloped forest land was wasteland (Hall 1992). Vegetation clearance was one of the improvements that was required by most settlement legislation in the 19th century, although areas of unused Crown land were temporarily listed as timber reserves.

The period from 1860 to 1890 is likely to have seen a variety of effects on *P. cinereus* populations. Although specific information for *P. cinereus* in Noosa Shire was not found, it is probable that ecological effects would have been similar to those in other regions of Australia in the early settlement phase (see Lee and Martin 1988; Martin and Handasyde 1999). The local Aboriginal tribe, the Kabi Kabi, may have killed *P. cinereus* for food and skins as did other tribes in South-east Queensland (Petrie 1982), and *P. cinereus* populations may have increased immediately after European settlement. It is possible that *P. cinereus* skins were used by early settlers, but Marshall (1966) does not believe this would have greatly affected population numbers. Timber cutting would have caused some localised disturbance. Hardwood species such as *E. acmenoides* (White Mahogany), *E. siderophloia* and *E. tereticornis* were used as pit props in the Gympie mines but the primary commercial timbers were softwoods. Early vegetation clearing for agriculture would have impacted locally on *P. cinereus* populations, but large areas of koala habitat remained intact. In addition, settlement was often fitful in these early years, as many settlers abandoned their land when conditions became too difficult. The landscape, during this phase, experienced perforation while the habitat that was left remained relatively intact, although disturbed by logging (*sensu* Forman 1995), and according to McIntyre and Hobbs (1999) would have been classed as a variegated landscape.

Between 1890 and 1910, the amount of farmland grew to over 45,000 ha. This period of landscape change driven by the rapid expansion of dairy farming, is considered to have had the most significant historical impact on *P. cinereus*, in terms of habitat loss. Reed *et al.* (1990), in their study into the distribution of *P. cinereus* in New South Wales, state that historic land clearing may explain the current distribution of *P. cinereus* in the Richmond and Clarence River valleys in northern New South Wales. This was an area where both beef and dairy cattle grazing occurred. Page (1970) specifically relates the arrival in the Noosa area of dairy farmers from the Richmond Valley with the introduction of more efficient ways of clearing vegetation. Knott *et al.* (1998) also found that land clearance in the 19th century associated with dairying explained the current apparent absence of *P. cinereus* from large tracts in the western half of Port Stephens Shire.

In addition to habitat loss, pelt hunting had a major effect on *P. cinereus* numbers in the first three decades of the twentieth century. Queensland was the last state to allow pelt hunting, although some level of protection for *P. cinereus*, in the form of closed seasons and the need for trapping permits, had been included under the *Native Animals Protection Act* of 1906. The last two open seasons in Australia, in 1919 and 1927, resulted in the sale of one million and 584,738 pelts respectively (Gordon and McGreevy 1978). Pelt hunting was considered as an easy source of income when economic times were hard, even in the closed season (Gordon and McGreevy 1978; Rolfe 2001). There is some debate over the long-term effect of pelt hunting, and *P. cinereus* were reportedly still common across Queensland in the 1920s (Marshall 1966; Gordon and McGreevy 1978; Rolfe 2001). It seems probable there is a link between habitat loss and the clustering of *P. cinereus* in unsustainable numbers in areas of remaining habitat, which may have given a misleading impression that they were still common (see Lunney and Leary 1988). *P. cinereus* populations suffered a severe decline across Queensland and in Noosa Shire in the late 1920s. The cause of this decline appears to have been an outbreak of disease, probably Chlamydia (Gordon and McGreevy 1978; Rolfe 2001). Southern Queensland was hit by a period of severe and prolonged drought that lasted though most of the mid to late 1920s and early 1930s (Office of Economic and Statistical Research 2002). This, combined with hunting and habitat loss, would have resulted in a high level of environmental stress. The severity and widespread nature of Chlamydia epidemics have been linked to environmental stress including habitat loss and drought (Lunney and Leary 1988; Melzer *et al.* 2000).

After a period of relative landscape stability between 1940 and 1960, there was another wave of development associated with increased urbanisation and the tourism industry. This change in the economic structure of the Shire over the past 40 years is reflected in the further loss of 35 per cent of remaining habitat. The present day landscape is classed as fragmented, with between 10-60% of habitat remaining (McIntyre and Hobbs 1999).

The effect on *P. cinereus* populations of this final stage of development is difficult to predict. *P. cinereus* has become an important tourist attraction in the Shire, as it has across the remainder of eastern Australia over the past decades (Hundloe *et al.* 1997). Increasing human population growth in Noosa Shire, both residential and tourist, has exposed *P. cinereus* to a range of threats posed by intensification of settlement. It is widely recognised that urban *P. cinereus* populations face increasing risks of mortality due to motor vehicle accidents and dog attacks, and the long-term viability of urban populations is not high (Pahl *et al.* 1990; Brown 1996; Lunney *et al.* 1996). Increased mortality is compounded by habitat loss and fragmentation as isolated habitat fragments are less likely to be recolonised by *P. cinereus* in the event of local extinctions (Pahl 1996; Lunney *et al.* 2002). One positive difference between Noosa Shire and some other areas of eastern Australia, is the presence of reasonably large areas of State Forest which contain significant *P. cinereus* habitat, unlike State Forests in some areas of New South Wales (Reed *et al.* 1990).

Conclusions

The current low densities of *P. cinereus* in Noosa Shire are a legacy of clearing of native forests by early European settlers. Habitat loss and fragmentation has increased in recent decades as a result of increased urban population growth in the coastal portion of the Shire. There is a clear link between various phases of landscape change and the subsequent loss of *P. cinereus* habitat. Habitat loss appears to be greatest at the beginning of periods of economic growth, following changes in the industrial base of Noosa Shire (from timber to dairying to tourism), with the additional drivers of government policy and cultural values and perceptions. The cumulative loss of habitat has been accompanied by increasing levels of habitat fragmentation, indicated by reduced patch size and increased patch linearity. As a consequence, *P. cinereus* populations in Noosa Shire have suffered a decline similar to other areas of eastern Australia such as Port Stephens, Iluka and Coffs Harbour in New South Wales (Lunney and Leary 1988; Knott *et al.* 1998; Lunney *et al.* 2000) and Logan Shire in South-east Queensland (Pahl *et al.* 1990; 1996). Further analysis of the temporal aspects of habitat change needs to be undertaken by combining the time series of maps documenting habitat loss into a single GIS layer showing time since clearing. The data could then be analysed against the current pattern of habitat occupancy as a basis for testing the hypothesis that there are relaxation periods between habitat loss and local extinction for *P. cinereus* populations which explain patterns of habitat utilisation.

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APPENDIX I

Appendix 1: Timeline of settlement in Noosa Shire, 1860 to 1999

Decadal Developments		Specific Events
1860s–Queensland Government legislates in favour of closer settlement rather than pastoral expansion, both for revenue raising and political ideals	**1863**	Timber getting begins focused on softwood species (*Toona ciliata, Araucaria cunninghamii, Agathis robusta, Callitris* spp.). Hardwood species used for building, fencing and pit props (*Eucalyptus acmenoides, E. siderophloia, E. microcorys* and possibly *E. tereticornis*) (Pedley 1979; Brown 2000).
1870s–Farms selected along river systems and logging tracks in Noosa. Mixed agriculture practiced, with main cash crop being sugar. Supplementary income from working in timber trade.	**1870**	Tewantin and Cooloothin town reserves established (Edwards 2001).
	1872	Messrs Luya, McGhie, Goodchap and Woodburn build Elanda Point sawmill and township. Logging carried out on lower Kin Kin Creek. 5000 ha selected for growing sugar (Edwards 2001).
	1876	Dath Henderson sawmill opens at Tewantin with logging at Cooroy (Edwards 2001).
1880s–Queensland Government continues to legislate for closer settlement, including providing help to settlers in the form of equipment and livestock. Timber industry in decline and local depression.	**1879**	Noosa headland reserved for town development (Edwards 2001).
	1884	Timber reserve of 3000 ha gazetted (Edwards 2001).
	1889	Timber reserve area increased to 25,000 ha. Village settlement of 513 ha established at Pinbarren (now Pomona) (Edwards 2001).
1890s–Economic depression climaxing in 1893, combined with severe flooding led to abandonment of many farms. Government legislated for co-operative settlement schemes. Dairying seen as way to broaden agricultural base and provide economically sound base for rural settlement.	**1891**	Village settlement at Cootharaba (failed after 8 months). Opening of rail link Yandina to Gympie (Edwards 2001).
	1892	Elanda Point sawmill closes (Page 1970).
	1893	Depression and severe flooding. Protestant Unity Group took up co-operative settlement area (2,400 ha) south of Pomona (Edwards 2001).
	1894	Depression ends and increased demand for land, supplied by releasing former timber reserves for selection (Edwards 2001). Agricultural Land Purchase Act passed to increase rural settlement.
	1898	Opening of butter factory in Gympie, supplied by surrounding farms (Edwards 2001)

APPENDIX I

Decadal Developments	Specific Events
1900s–Period of prolonged drought, climaxing in 1903, reduced numbers of farms and livestock. End of drought brought renewed interest in land and over the decade approx 10,000 ha of land was released to dairy farmers.	**1903** Severe drought, ending in 1904 (Office of Economic and Statistical Research 2002).
	1905 Risley Group from NSW purchase dairy land near Cooran and systematically clear vegetation and plant pasture (3,200 ha). Other groups select land for dairying at Skyring's Creek (5,800 ha) (Page 1970).
	1907 Former Dath Henderson land at Cooroy released for dairying (Edwards 2001).
	1909 Cooroy township established (Edwards 2001).
1910–1959 - The growing population lead to the formation of Noosa Shire in 1910. Dairy farming continued to expand in the 1920s and provided a stable income for many families throughout the 1930s to the 1950s. Tourism and the timber remained important components of Noosa's industrial base.	**1910** Noosa Shire formed (Edwards 2001).
	1912 Kin Kin Butter Factory opened (Page 1970).
	1915 Cooroy Butter Factory opened (Page 1970).
	1919 Pomona Butter Factory opened (Edwards 2001).
	1928 Completion of tarred main roads in Shire (Edwards 2001).
	1929 Construction of bridges over Lakes Doonella and Weyba by T.M. Burke & Co, so road access to Noosa Heads. Start of housing construction at Sunshine Beach (Edwards 2001).
	1935 230 lots at Sunshine Beach sold (Edwards 2001).
	1957 4800 ha former dairying land resumed for forestry (Edwards 2001).
	1959 Crown Land Development Act passed, linking development to road building.
1960s – The dairy industry was declining due to changing market and social conditions. Change to beef cattle. Movement of people into urban areas and subdivision of former farms. Growth of environmental awareness.	**1960** Completion of coast road by T.M. Burke and development of housing estate at Peregian Beach (Edwards 2001).
	1962 Formation of Noosa Parks Development Association, partly to prevent sandmining of Teewah Coloured Sands (Edwards 2001).
	1965 302 dairy farms in Shire (Edwards 2001).
	1969 Development of Hays Island and Hastings Street first proposed (Cato 1989).
1970s-1990s – Continuing urban development of existing towns and subdivision of rural properties. Continuing environmental activism. Increasing tourism industry. Gazetting of conservation areas.	**1972** Development of Hays Island and Hastings Street (Cato 1989).
	1973 Land purchased to build canal estate at Noosaville (Edwards 2001).
	1975 Cooloola National Park formed (Edwards 2001).
	1980 43 dairy farms in Shire (Edwards 2001).
	1989 Construction of Noosa Waters canal estate (Edwards 2001).