Decline in the distribution of the Koala *Phascolarctos cinereus* in Queensland

Greg Gordon[1], Frances Hrdina[2] and Ross Patterson[3]

[1] PO Box 636, Paddington Qld 4064; ggordon@gil.com.au (corresponding author).
[2] 30/38 Dundee Rd, North Maclean Qld 4280.
[3] Queensland Parks and Wildlife Service, PO Box 64, Bellbowrie Qld 4070.

ABSTRACT

We assessed decline in the distribution of *P. cinereus* in Queensland over the last century using historical data from *P. cinereus* surveys and the Queensland State Archives to measure change in extent of occurrence and area of occupancy. Broad distribution (extent of occurrence, measured with a minimum convex polygon) has contracted by about 27% and area of occupancy (measured with a 30 minute grid) by about 31%. The degree of contraction in area of occupancy correlates with the estimated extent of habitat loss, supporting suggestions that habitat loss has been, and may still be, the major threat to koalas in Queensland. Contraction in the overall range has occurred on the northern and western margins of the distribution (the Wet Tropics, Gulf Plains, Mitchell Grass Downs, and Mulga Lands Bioregions). Distribution showed a latitudinal change during the harvest period in the early 20th century, with an increase in area of occupancy in central Queensland and a decrease in southern and northern Queensland. This correlates with corresponding changes in population size. Analysis of distribution does not provide support for listing *P. cinereus* as vulnerable in Queensland or the South East Queensland Bioregion. Problems in measurement of area of occupancy and extent of occurrence are discussed. It is difficult to measure the areas accurately due to difficulty in meeting the underlying assumptions of the techniques.

Key words: koala, *Phascolarctos cinereus*, distribution, conservation status, koala decline

Introduction

We used historical data on the occurrence of the Koala *Phascolarctos cinereus* in Queensland to assess long-term change in its distribution. These data will also assist in assessing change in its conservation status. We also discuss the conservation status of *P. cinereus* in Queensland and the South East Queensland Bioregion. There is a scarcity of detailed and systematic information on *P. cinereus* distribution and abundance over extensive areas, and conclusions on status are generally based on scanty data, or extrapolations from local surveys.

Views on the conservation status of *P. cinereus* are highly polarised and there is continuing controversy over status. The Australian Koala Foundation made a submission to the Commonwealth Government in 2004 proposing that it should be listed as vulnerable nationally, reflecting a common feeling among many conservationists about its status. Phillips (2000) argued that *P. cinereus* should be listed as vulnerable based on large declines in a number of local and regional populations, and stated that "a pessimistic forecaster might suggest that there is a real risk of koalas becoming endangered in the next 10-15 years". However, others have argued that it has a much better status than vulnerable. Melzer *et al.* (2000) summarised current knowledge of the conservation status of *P. cinereus* populations. They suggested that habitat destruction is the greatest threat to *P. cinereus* and that it had undergone a decline in distribution and abundance of greater than 50%, but was not vulnerable. *P. cinereus* was classified as Lower Risk (near threatened) in the Marsupial and Monotreme Action Plan (Maxwell *et al.* 1996) and was not considered vulnerable in the National Koala Conservation Strategy (ANZECC 1998) or by the Australian Government (Martin and Handasyde 1999).

The Scientific Advisory Committee of the Queensland Minister for Environment assessed the status of *P. cinereus* in Queensland in 2003. The Committee advised that it should be classed as common wildlife in the State, but considered it to be vulnerable in the South East Queensland Bioregion (Sattler and Williams 1999). Subsequently, the Government listed it as vulnerable in the Bioregion based on "the size of the current population, the rate of habitat loss and known mortality rates" (media statement, Mr P. Beattie, Queensland Premier, 5 March 2004).

Gordon and Hrdina (2005) discussed the change in populations of *P. cinereus* in Queensland over the past two centuries. It is thought that population size increased greatly in southern and central Queensland from early settlement until the early 20th century (i.e. a population eruption occurred, Caughley 1970), then declined to a lower level. In northern Queensland, major fluctuation in numbers does not seem to have occurred, although abundance probably has declined overall. There were marked regional differences in the timing of these population changes. Changes occurred earlier in southern Queensland than in central Queensland.

Community response surveys were carried out in Queensland in 1967 (Kikkawa and Walter 1968), 1977 (Campbell *et al.* 1979) and 1986-1988 (Patterson 1996). The results showed that *P. cinereus* was widely distributed and, at a broad scale, still occupied most of its original range, although there was thought to be a major decline at a more local level. Kikkawa and Walter (1968) concluded that numbers had declined significantly, suggesting they might be less than 10% of previous levels, and that distribution had contracted. Patterson (1996) reported a contraction in distribution in the far north and on the western margin of the range. He also identified regions where population concentrations occurred and found that *P. cinereus* had apparently disappeared from a number of localities. In August 1928, the Nature Lovers League surveyed *P. cinereus* in Queensland by writing to Shire Councils, Dingo Boards and municipal Councils with questions on the number of *P. cinereus* in the state, and whether they were in favour of protection (Anonymous 1929; Herbert 1929). The aim of the survey was to determine the effect of the August 1927 "open season on the distribution and numbers of native bears over the whole state" (Herbert 1929). Only a summary of the survey results has survived. Seventy-two of the 102 respondents (71%) stated or implied that *P. cinereus* was present in their district, indicating that *P. cinereus* had a wide distribution (Table 1). However, the great majority (90%) also believed that *P. cinereus* was scarce (or absent) in their districts. Only three replies stated that they were plentiful.

Table 1. Results of the 1928 Koala Survey by the Nature Lovers League, copied from Herbert (1929). The "Category" column shows the number of replies from shire councils, Dingo Boards and municipal Councils that fall in each group. See text for more details.

Category	No. of replies
Bears plentiful – not in favour of protection	1
Bears plentiful – in favour of total protection	2
Bears practically exterminated or very scarce	69
No bears seen since open season	2
No information as to number of bears, but protection favoured	7
No bears in district – protection favoured	6
No bears in district – no opinion expressed	15
Total	**102**

Methods

P. cinereus point location data were compiled from as many sources as possible covering the period from 1890 to 2000. The data were used to assess change in area of occupancy and extent of occurrence (IUCN 2001) over this period in Queensland, and in the South East Queensland Bioregion. Decline in distribution may consist of both local contraction in distribution (measured by area of occupancy) and contraction of the broad distribution of a species (measured by extent of occurrence).

Data sources

Data were obtained from the following sources (Table 2): correspondence in the Queensland State Archives associated with monitoring of populations during the *P. cinereus* harvest (Gordon and Hrdina 2005); the 1967 Koala Survey by the Wildlife Preservation Society of Queensland (Kikkawa and Walter 1968); the 1977 Koala Survey by the Wildlife Preservation Society of Queensland (Campbell *et al.* 1979); the 1986-1988 National Koala Survey (Patterson 1996); and Queensland Environmental Protection Agency databases, including the WildNet database, NatureSearch records and data from Dr David McFarland of the Environmental Protection Agency. In order to reduce bias towards local areas, data analysis was based on statewide datasets rather than incidental records or local surveys, except where the latter two sources were appropriate. The Statewide datasets comprised the State Archives data, the two Wildlife Preservation Society surveys and the National Koala Survey.

State Archives data - monitoring for the *P. cinereus* harvest. Queensland had an unregulated *P. cinereus* harvest up to 1906, followed by a regulated harvest from 1906 to 1927 (Hrdina and Gordon 2004). In order to monitor *P. cinereus* status for management of the harvest, the Queensland Department of Agriculture and Stock sent annual questionnaires on status to offices of the Department and to all police stations and Lands Department offices (Hrdina and Gordon 2004; Gordon and Hrdina 2005), commencing in about 1920. These surveys record the opinions of departmental officers and police on the local status of *P. cinereus*. For the police at least, reply appeared to be obligatory, so that a State-wide account of *P. cinereus* occurrence and abundance was obtained. From the late-1920s, questionnaires were

Table 2. Number of *P. cinereus* records by source, in 20-year groups. QSA = Queensland State Archives; WPSQ = Wildlife Preservation Society of Queensland; NKS = National Koala Survey; EPA = Queensland Environmental Protection Agency.

	QSA	WPSQ 1967	WPSQ 1977	NKS	EPA	Total
1881-1900	5	194	0	3	8	210
1901-1920	12	219	0	9	4	244
1921-1940	228	35	0	49	15	327
1941-1960	1	244	0	21	7	273
1961-1980	0	413	56	78	0	547
1981-2000	0	0	0	1789	4693	6482
Total						**8083**

sent to specialised Fauna Rangers. A small number of records was also obtained from other correspondence in the Archives (principally from landholders). The records cover the period from 1890 to 1942. Questions used in these surveys were designed to provide information on *P. cinereus* abundance, rather than presence. Questions generally asked if numbers were sufficient or insufficient for a harvest. Gordon and Hrdina (2005) provide a fuller description of the surveys.

1967 WPSQ Koala Survey. During the 1967 survey, questionnaires were used to elicit information on the presence of *P. cinereus* (Kikkawa and Walter 1968). Survey forms were sent to primary schools throughout the State. Some responses were also obtained from individuals in response to publicity about the survey. Since some of the survey questions asked for information on occurrence at earlier times, the data include records for both 1967 and earlier periods, including the years 1942 ("25 years ago") and 1917 ("50 years ago"), and prior to 1900 ("before 1900").

1977 WPSQ Koala Survey. During the 1977 survey, similar procedures were used as in 1967, although fewer responses were obtained (Campbell *et al.* 1979).

1986-1988 National Koala Survey (NKS). This survey was also based on the use of questionnaires, employing a range of techniques targeting people in rural areas, including mailing of survey forms to rural residents and landowners, and publication of forms in regional newspapers and Department of Primary Industry newsletters. Field searches were also carried out with assistance from the community, and incidental records of *P. cinereus* were collected. A large number of records was obtained (Patterson 1996).

Environmental Protection Agency (EPA) databases. WildNet is a database that includes wildlife records collected by the Queensland Environmental Protection Agency, including *P. cinereus* records collected by the NatureSearch program, among other sources. NatureSearch was a project developed with the aim of stimulating wildlife survey and wildlife reporting by members of the community. It includes wildlife surveys targeted at local areas, and incidental wildlife records. Additional records were obtained from data collated by Dr D. McFarland, of the EPA, and one of the authors (GG). These databases include incidental records and records gained during small scale *P. cinereus* surveys targeted at local areas.

Limitations of the data. As the data were not obtained during systematic surveys, survey effort depended on the presence of observers, and the results may therefore show bias towards areas where observers occur. However, all except the 'EPA' datasets were based on surveys that extended throughout the state, although presumably patchily, and yielded comprehensive State-wide sets of data. This should reduce the level of bias towards regions or local areas. The pre-1967 records for the WPSQ 1967 survey were based on asking respondents if *P. cinereus* was present 25 years ago, 50 years ago and before 1900. Due to limitations of people's memory, this kind of data is inherently of low reliability. The locations of many records are of low precision due to the nature of the surveys. Data are much more extensive for later years than earlier years (Table 2) and the maps may therefore be biased towards showing better status in the latter period. However, as this is the only information available about past distribution, and given the continuing controversy over *P. cinereus* status, we consider that its use is justified in drawing cautious inferences about status. IUCN (2001) justifies making use of available data and making decisions in the face of uncertainty.

Data preparation

State Archives data. Harvest monitoring records were only included in the data if the correspondence in the Archives definitely indicated that *P. cinereus* was present in a region. Precise locations were not usually given. Location of the record was therefore assigned to the location of the government office, property homestead or other centre, and it may be inferred that precision of the records is relatively low.

1967 Koala Survey. The original data from the 1967 Koala Survey (Kikkawa and Walter 1968) has been lost. However, one of the authors (GG) has a copy of the data on index cards. These data were entered into an electronic database. Latitude/longitude coordinates were then read from GIS (ArcView) maps or from hard copies of topographic maps. The locations in the copied data were usually given as descriptions of approximate distance and direction from towns or properties in the following form, e.g. "koala sighted 12 miles north-north-east of Roma".

1977 Koala Survey. The original data from the 1977 Koala Survey has been lost and we did not succeed in locating any copies of the data. The published survey map (Campbell *et al.* 1979) appears to be the only remaining record of the data. This map was therefore scanned, saved as a ".jpg" image and registered in MapInfo v 4.0. Coordinates of locations were then read from the map. Data are only available for the year 1977.

1986-1988 National Koala Survey. Data were extracted from an electronic database, held by one of the authors (RP), containing the survey results. Data included *P. cinereus* sightings and *P. cinereus* sign, and include historical records from earlier years.

WildNet and NatureSearch. Records were extracted from electronic databases held by the Environmental Protection Agency.

Data analysis

A total of 8083 records was available for the years 1881-2000, mainly from the last 20 years, 1981-2000 (Table 2). Maps of *P. cinereus* distribution were prepared for 20-year and 30-year periods between 1881 and 2000, using Arcview v. 3.1. Maps were assessed for evidence of contraction or expansion in range using the IUCN (2001) measures, area of occupancy and extent of occurrence.

Area of occupancy in Queensland. Area of occupancy in Queensland was calculated using a 30-minute grid. For comparisons between populations in the early and late 20th century, the periods 1899-1928 and 1917-1936 were chosen in the early 20th century in order to maximise the number of locations. These early records mainly came from the 1967 survey (i.e. historical records from "50 years ago" and "before 1900") and from State Archives data. Area of occupancy for each of these periods was compared with that for 1981-2000. Data for the period 1981-2000 were obtained from the 1789 National Koala Survey records (mainly representing the years 1986-88) (Table 2). A total of 676 locations was used in 1899-1928, and 533 locations in 1917-1936. To ensure that area calculations were based on equal numbers of locations, random samples of 676 and 533 locations respectively were selected from the 1981-2000 data for the analysis. For each analysis, 10 random samples were chosen, area of occupancy was calculated for each sample, and the mean of the 10 areas was used for comparison with the two early 20th century periods. Change in area of occupancy was also assessed for the period, 1881-1940, which was taken to represent the harvest period. Area of occupancy was calculated for three 20-year periods, 1881-1900, 1901-1920 and 1921-1940, using a similar approach as described above. As 210 locations were available for the earliest period, 10 random samples of 210 records each were used to calculate areas for the following two periods.

Extent of occurrence in Queensland. Data were selected as described above for area of occupancy, including 10 random samples of the 1981-2000 data. Extent of occurrence was calculated for each sample, and the mean of the 10 areas was used for comparison with the two early 20th century periods. Extent of occurrence was calculated with two methods, minimum convex polygons and kernel estimation (White and Garrott 1990). The program *Home Range Extension for ArcView®GIS* (Rodgers and Carr, Ontario Ministry of Natural Resources, Canada) was used to generate minimum convex polygons enclosing the records for each period. Kernel contours were also generated with *Home Range Extension for ArcView®GIS*, with 95% utilisation probabilities (contours) and the smoothing parameter set to 0.1. Areas of the minimum convex polygons and kernels were calculated in Arcview 3.1 with the Arcview extension Xtools (version 15 Sep 2003, Mike DeLaune, Oregon Department of Forestry), and with the map set in the Albers Equal-Area projection (Parameters: Central meridian: 145.9782, Reference latitude: -19.7331, Standard parallel 1: -26.2103, Standard parallel 2: -13.2559). Note that polygon areas include sections of ocean along the eastern boundary (e.g. Figure 2). The terrestrial area for the period 1981-2000 was also calculated using all available data (6482 records) to determine the full current terrestrial distribution of *P. cinereus* in Queensland.

Area of occupancy in South East Queensland Bioregion. *P. cinereus* was listed as vulnerable wildlife in the South East Queensland Bioregion by the Queensland Government in 2004. Distribution in the Bioregion was therefore investigated to determine if the historical data revealed a change in distribution. Area of occupancy was determined on a 20-minute grid overlaid over the locations. Data sources were the same as described above for area of occupancy in Queensland. The period 1899-1928, with 216 locations, was chosen in the early 20th century in order to maximise the number of locations. Area of occupancy for this period was compared with that for 1981-2000. For the later period, a data subset of 216 records was selected in 10 random samples, as described above for area of occupancy in Queensland.

Results

Change in area of occupancy in Queensland

Area of occupancy decreased by 16% from 1899-1928 to 1981-2000 (Chi-Square = 3.391 with 1 d.f., P = 0.066) (Table 3, Figure 1), and underwent a significant decline of 31% from 1917-1936 to 1981-2000 (Chi-Square = 12.304 with 1 d.f., P = 0.0005) (Table 3, Figure 1). The difference between the two early periods is due to four additional locations present in the 1917-1936 data, including an outlying Cooktown record, which lead to an increase in area for that period. This data set is therefore assumed to be the most accurate, and the decline is taken as 31%.

Latitudinal change in area of occupancy (Table 4) showed no significant change from 1899-1928 to 1981-2000 (Chi-Square = 1.43 with 2 d.f., P = 0.49), and from 1917-1936 to 1981-2000 (Chi-Square = 3.59 with 2 d.f., P = 0.17).

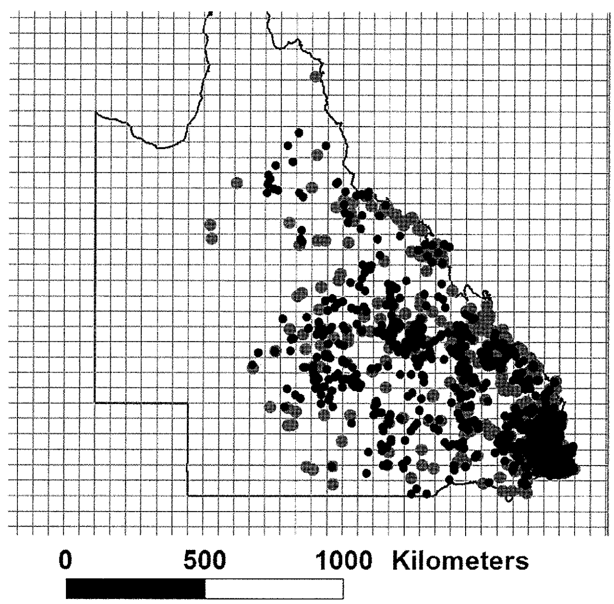


Figure 1. Queensland with 30-minute grid showing area of occupancy. 1881-1936, grey circles; 1981-2000, black circles. The records for 1881-1928 and 1917-1936 are combined in the figure, giving a total of 745 records. The data for 1981-2000 include 1789 NKS records.

Table 3. Area of occupancy in Queensland. The table shows the number of 30-minute grid cells with *P. cinereus* present, classified by year group. Decrease is calculated as percentage decrease in number of occupied grid squares.

Period	No. of locations	No. of grid cells occupied	Decrease in area
1899-1928	676	147	
1981-2000	676	123	16%
1917-1936	533	153	
1981-2000	533	107	31%

Table 4. Area of occupancy in Queensland by latitude from 1917-1936 to 1981-2000, and from 1899-1928 to 1981-2000. The table shows the number of 30-minute grid cells with *P. cinereus* present, classified by year group and degrees of latitude.

Latitude (degrees)	No. of grid cells	
	1899-1928	1981-2000
15-17 (far north Qld)	0	0
17-21 (north Qld)	20	11
21-25 (central Qld)	57	50
25-29 (south Qld)	70	62
Total grid cells	147	123
No. of koala records	676	676
	1917-1936	1981-2000
15-17 (far north Qld)	1	0
17-21 (north Qld)	23	8
21-25 (central Qld)	60	44
25-29 (south Qld)	69	55
Total grid cells	153	107
No. of koala records	533	533

Change in extent of occurrence in Queensland

Extent of occurrence contracted by 16% between 1899-1928 and 1981-2000 (Table 5), and by 27% between 1917-1936 and 1981-2000 (change in area of MCP, Table 5, Figure 2). Kernel estimation methods also showed a substantial decrease in area (23% and 29% respectively, Table 5, Figure 3). The apparent increase in extent of occurrence from 1899-1928 to 1917-36 (area of MCP - 920,804 s.km to 1,019,080 s.km., Table 5) is due to a single outlying record near Cooktown in the second period. If this record is deleted, the area in 1917-1936 is 915,532 s.km., which is almost the same as for 1899-1928 (area of MCP, Table 5). It is likely, therefore, that there was little real difference in koala distribution between the two periods, and the 1917-1936 data set, with a decline of 27%, is assumed to be the most accurate. Current extent of occurrence is shown most accurately by the full set of data for the period 1981-2000 (6482 records), giving a terrestrial area of 872,358 s.km. (area of MCP, Table 5, Figure 2).

P. cinereus survives in all Bioregions originally occupied other than Gulf Plains Bioregion, where there is a record from Croydon on the eastern margin of the Bioregion in 1927, and Cape York Peninsula Bioregion, where there is a record on the southern margin near Cooktown in 1930. A contraction has occurred at the northern, north-western and south-western margins of the range in Wet Tropics, Gulf Plains, Mitchell Grass Downs, and Mulga Lands Bioregions (Figure 2).

Area of occupancy – South East Queensland Bioregion

Area of occupancy in the South East Queensland Bioregion showed a non-significant decrease of 23% from 1899-1928 to 1981-2000 (Chi-square = 2.895 with 1 d.f., P = 0.089) (Table 6, Figure 4).

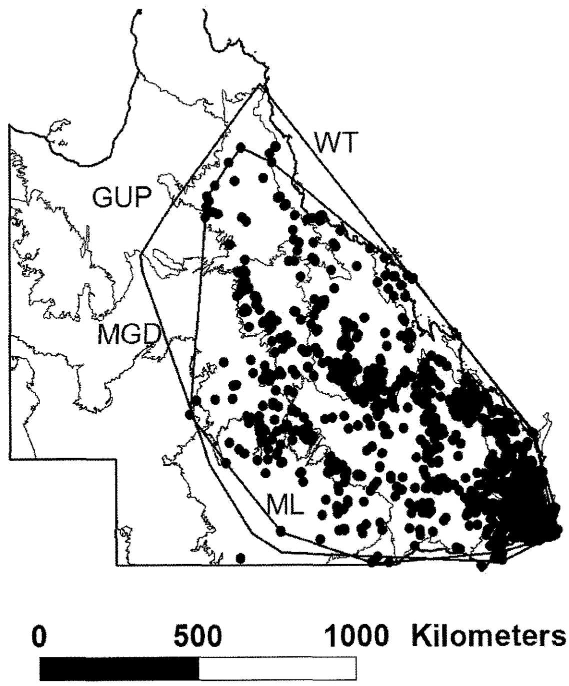


Figure 2. Queensland, with Bioregion boundaries, showing extent of occurrence: 1917-1936 - larger polygon; 1981-2000 - smaller polygon. Polygon for 1917-1936 is based on 533 records and the polygon for 1981-2000 is based on 1789 NKS records. Solid circles show all *P. cinereus* locations for the period 1981-2000 (total 6482 records), indicating current *P. cinereus* distribution in Queensland. Bioregions: GUP = Gulf Plains, MGD = Mitchell Grass Downs, ML = Mulga Lands, WT = Wet Tropics.

Table 5. Extent of occurrence in Queensland. Areas (sq. km.) are shown as the total area within a minimum convex polygon and a 95% kernel respectively, except for the last figure (6482 locations), which shows terrestrial area only.

Period	No. Locations	MCP Area (sq. km.)	Decrease	Kernel Area (sq. km.)	Decrease
1899-1928	676	920,804		677,025	
1981-2000	676	775,594	16%	522,645	23%
1917-1936	533	1,019,080		703,091	
1981-2000	533	746,800	27%	497,987	29%
Based on all locations:					
1981-2000	6482	872,358		847,844	

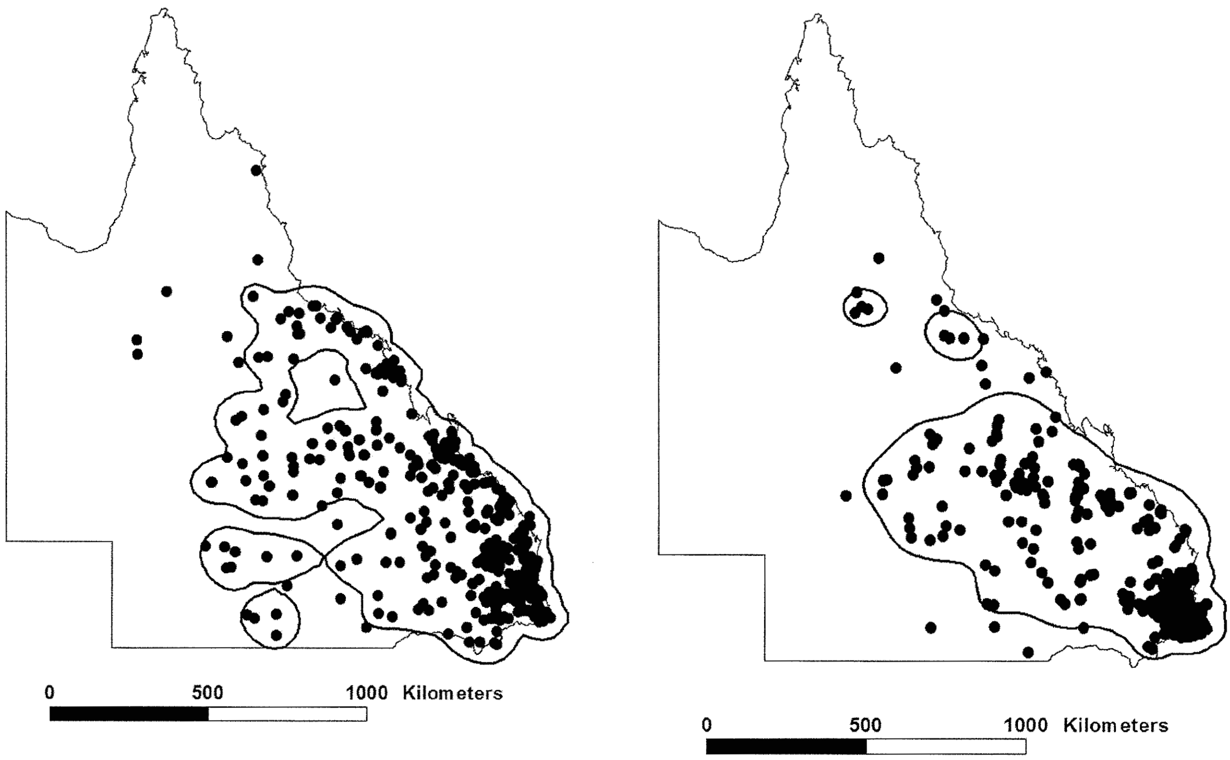


Figure 3. Queensland, showing 95% utilisation kernel boundaries. Left: Distribution in 1917-1936 based on 533 records. Right: Distribution in 1981-2000 based on a random sample of 533 records (from the 1789 NKS records). Solid circles show *P. cinereus* locations for the periods.

Table 6. Area of occupancy in the South East Queensland Bioregion, calculated on a 20-minute grid. The table shows the number of 20-minute grid cells with *P. cinereus* present. Total number of cells in SEQ Bioregion = 70.

Period	No. of locations in SEQ	No. of grid cells occupied	Decrease
1899-1928	216	44	
1981-2000	216	34	23%

Change in area of occupancy during the harvest period

Area of occupancy in Queensland showed a significant decline of 22% over the harvest period from 1881-1900 (108 grid cells) to 1921-1940 (84 grid cells) (Table 7, Figure 5) (Chi-square = 4.0035 with 1 d.f., P = 0.045). The decline occurred in the final decade, 1920-1940 (Table 7). Area of occupancy was also analysed by latitude to detect any latitudinal change in distribution over the harvest period from 1881-1900 to 1921-1940 (Table 7). Area of occupancy declined in southern and northern Queensland, and increased in central Queensland in the final decade, 1921-1940 (Table 7) (Chi-square = 6.0998 with 2 d.f., P = 0.047).

Discussion

Analysis of data and measurement problems

The earlier surveys were based mainly on circulation of questionnaires to public servants or schools. The later survey (NKS) used various methods to target rural residents and landowners. It is possible that this

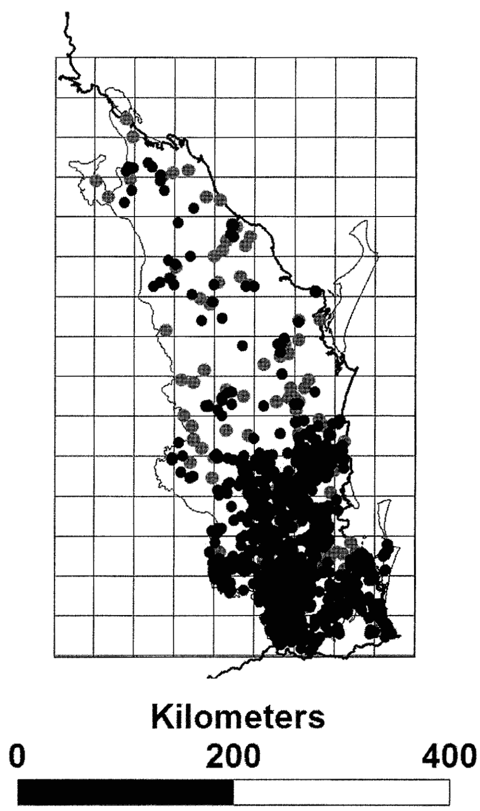


Figure 4. South East Queensland Bioregion with 20-minute grid. Area of occupancy: 1899-1928, grey circles; 1981-2000, black circles. The data include 216 records for 1899-1928 and 1179 NKS records for 1981-2000.

Table 7. Area of occupancy in Queensland by latitude over the harvest period from 1881-1900 to 1921-1940, using all records. The table shows the number of 30-minute grid cells with *P. cinereus* present, classified by 20-year group and degrees of latitude.

Latitude (degrees)	No. of occupied grid cells		
	1881-1900	1901-1920	1921-1940
17-21 (north Qld)	15	17	9
21-25 (central Qld)	35	35	42
25-29 (south Qld)	58	58	33
Total grid cells	108	110	84
No. of koala records	210	210	210

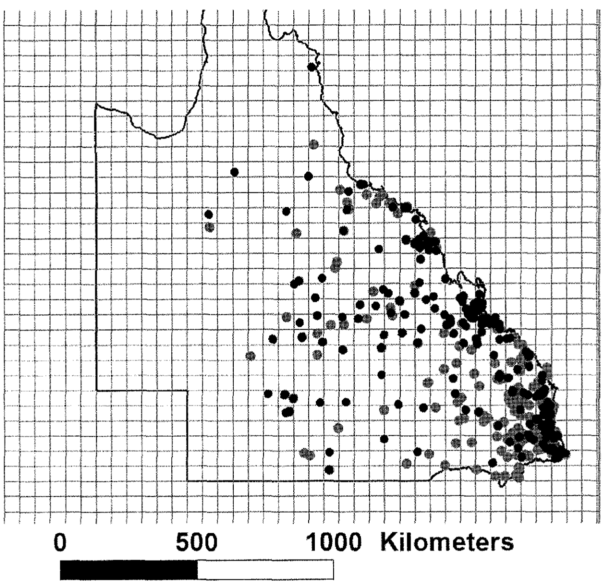


Figure 5. Queensland with 30-minute grid showing area of occupancy during the harvest period. 1881-1900, grey circles; 1921-1940, solid circles. The data include 210 records for 1881-1900 and 327 records for 1921-1940.

survey achieved a more comprehensive coverage of the State (with fewer gaps), resulting in calculation of relatively greater values for area of occupancy and extent of occurrence than for the earlier surveys. This consideration implies that there may be an unknown error in the calculation of change from 1899-1928 and 1917-1936 to 1981-2000, depending on the importance of differences in survey methods. If so, the calculated declines (31%, Table 3, 27%, area of MCP, Table 5) are more likely to be underestimates than overestimates, as the NKS survey is the most comprehensive survey that has been undertaken.

Accurate measurement of change in area of occupancy and extent of occurrence between two periods depends on the assumptions that a full description of the species distribution was available, or that systematic surveys with equal survey effort were carried out at both times. Often, however, there is only partial knowledge of distribution for one or both times. It is clear from discussion in IUCN (2001) that it is intended that IUCN criteria may be used relatively loosely if necessary, for example if there is uncertainty about distribution. When assessing threatened species, it is likely that there will commonly be some uncertainty about distribution, particularly the historical distribution. Here, we measured the areas using equal numbers of records for each period, in an attempt to equalise survey "effort". However, the surveys were not based on systematic sampling, different methods were used for each survey, and it is not certain if the historical distribution was fully known. In addition, minimum convex polygons (used to measure extent of occurrence) often include large areas that are not utilised by the species whose range is being studied, and may only provide an approximate estimate of change in area of distribution. Many attempts to assess change in distribution of Australian mammals will suffer from measurement problems, as the historical distribution of many species is poorly known. Although the historical distribution of *P. cinereus* in Queensland is much better known than it is for most other native mammals (as a result of the harvest monitoring and the 1967 WPSQ survey), it is still difficult to measure the *P. cinereus* decline accurately.

Contraction in local distribution

Queensland has been subject to extensive clearing of eucalypt forest and woodland since European settlement. Based on vegetation modelling, the Australian Koala Foundation (2004) estimated that there was a loss of 34% of potential *P. cinereus* habitat (i.e. *Eucalyptus* and *Callitris* forest and woodland) in Queensland and 46% in Australia. They also suggested that clearing that has occurred since their study would take total national loss to over 50%. These figures strongly imply that there has been a substantial contraction in local distribution of *P. cinereus* since European settlement. The estimated decline in area of potential habitat, 34%, is slightly larger than the decline in area of occupancy, 31%, and is unlikely to differ significantly. Although both estimates are imperfect, the relatively close correlation between loss of potential habitat and contraction in area of occupancy supports suggestions that habitat loss has been, and may still be, the major threat to koalas in Queensland. The Australian Koala Foundation (2004) calculation of habitat loss was approximate – all *Eucalyptus* and *Callitris* forest and woodland was assumed to be "potential koala habitat". It is likely that the "potential koala habitat" of the study includes much non-habitat or marginal habitat. Not all eucalypt and *Callitris* vegetation ranks equally as koala habitat, and the estimate is probably too high due to inclusion of relatively high proportions of non-habitat in the cleared areas. For example, in recent years, much of the eucalypt woodland that has been cleared for pastoral development in western Queensland has been low quality habitat, whereas the high quality riverine habitats are less affected by clearing (Gordon *et al.* 1988; Munks *et al.* 1996; Sullivan *et al.* 2004).

In the South East Queensland Bioregion, there was a smaller contraction in area of occupancy (23%, Table 6) than elsewhere, which was not statistically significant. It is possible that there has been fine scale contraction in distribution that was not detected in this study due to the large size of grid cells (30- and 20-minute grids).

Many records used for the later years in this study came from the 1980s (i.e. the NKS survey). The calculated distribution for the most recent periods therefore will not fully reflect the effect of more recent broad acre clearing occurring in western Queensland in the 1990s. It is likely that this clearing has increased the size of the decline slightly.

P. cinereus persists throughout almost 70% of its former range despite extensive clearing and habitat fragmentation. Some authors consider that habitat fragmentation is a serious threat for *P. cinereus* (e.g. Hume 1990; Pahl *et* al. 1990; ANZECC 1998; Seabrook *et al.* 2003). McAlpine *et al.* (2006) showed that fragmentation was important in Noosa Shire, Queensland. Koala occurrence increased with the area of all forest habitats and habitat patch size, and decreased with distance between forest patches, density of forest patches, and density of sealed roads. However, other studies (e.g. Gordon *et al.* 1990; White 1999) have found that *P. cinereus* populations have coped with habitat fragmentation, occurring and persisting successfully in extensively cleared farmland habitat, possibly because the cleared areas are relatively free of hazards in the form of traffic and dogs. At least some populations therefore have a relatively high tolerance for partial clearing and habitat fragmentation. It is likely that the impact of habitat loss and fragmentation on *P. cinereus* populations is complex, and requires consideration of other factors than total area cleared, including the degree and nature of fragmentation, the nature of the remaining vegetation, and habitat type and quality. Weigand *et al.* (2005) suggested that "predicting fragmentation effects requires a good understanding of the biology and habitat use of the species in question and that the uniqueness of species and the landscapes in which they live confound simple analysis."

State-wide distribution

It is generally thought that *P. cinereus* numbers in Queensland expanded following European settlement (Gordon and Hrdina 2005), reaching a peak in the late 19th or early 20th century. Similar changes occurred in New South Wales and Victoria, but somewhat earlier (Lunney and Leary 1988; Martin and Handasyde 1999). If the area of distribution also peaked then, it is likely that the range contraction (up to about 27% in extent of occurrence) since about 1900 is the maximum that has occurred. The contraction in range that took place over the two centuries since European settlement should not exceed this figure, and may even be smaller.

As was reported also by Patterson (1996), contraction in range has occurred on the northern and western margins of the distribution, where there has been relatively little broad acre clearing of eucalypt forest and woodland. The Gulf Plains, Mitchell Grass Downs, and Mulga Lands Bioregions are among the regions least affected by tree clearing within the *P. cinereus* range; the western margins of this zone have greater than 90% of native vegetation remaining (Morgan 2001). Therefore, the local extinction of *P. cinereus* here presumably was not caused by broad acre clearing. As these *P. cinereus* populations were at their range margins, they may have been more susceptible to selective clearing or habitat fragmentation, or degradation of watercourses and their fringing tree communities than *P. cinereus* farther east. Watercourses provide important *P. cinereus* habitat in inland regions (Gordon *et al.* 1988; Munks *et al.* 1996; Sullivan *et al.* 2004).

South East Queensland Bioregion

P. cinereus had a consistently extensive distribution in the South East Queensland Bioregion from 1917-1936 to 1981-2000, with a small, non-significant, decrease in area of occupancy. They do not support conclusions that there has been any marked decline in broad distribution in the region due to loss of habitat. However, local contraction in distribution may have occurred at a scale too fine to be detected in this analysis, which is based on use of a 20-minute grid. Secondly, there has been significant loss of *P. cinereus* habitat in the south-eastern coastal area (approximately from Noosa, through Brisbane, to the Gold Coast) (H. Preece, pers. comm. 2003, Qld EPA) where there has been clearing for urban expansion and associated works. It is likely that *P. cinereus* trends in the Bioregion have been markedly different between this coastal area and the more westerly and northern sections, with a strong decline in the south-eastern coastal area and a lesser decline elsewhere.

Although *P. cinereus* has been listed as vulnerable in the SEQ Bioregion, this analysis of *P. cinereus* distribution does not provide support for the listing (Table 6). However, to determine status in the bioregion, the *P. cinereus* population should also be assessed against the other IUCN criteria for vulnerable, based on population size, trends in populations, and population modelling, which were not used in this study.

Impact of the Koala Harvest

The *P. cinereus* harvest correlates with a small change in distribution – i.e. an overall decline in area of occupancy, accompanied by an increase in central Queensland and declines in southern and northern Queensland. These latitudinal trends in area of occupancy correlate partly with the trends in population size at the time of the regulated harvest (1906-1927): numbers increased in central Queensland, declined in southern Queensland and showed little change in northern Queensland (Gordon and Hrdina 2005). These results are based partly on the same data. However, they differ in that the results in the earlier paper were based wholly on State Archives data, whereas this paper has a large number of records from other sources for the period 1881-1940 (Table 2). It is of interest that the pattern shown in 1921-1940 of an expansion in central Queensland relative to other regions (Table 7), has reversed in the 1981-2000 data, where central Queensland again shows a relatively smaller area of distribution (Table 4). Factors causing the disparity in 1921-1940 had apparently diminished in importance by 1981-2000. Gordon and Hrdina (2005) discuss possible causes of these population changes during the harvest period. It is difficult to separate the effect of harvesting from that of other factors such as changes in vegetation due to clearing and dieback. However, Gordon and Hrdina concluded that the population trends resulted mainly from changes in land use and vegetation, rather than the harvest.

Status of *P. cinereus*

As it has been suggested that *P. cinereus* is vulnerable in Australia (Phillips 2000; Australian Koala Foundation 2004), the data were assessed for evidence of vulnerable status in Queensland. *P. cinereus* distribution contracted by up to about 31% over about 100 years, showing that *P. cinereus* in Queensland do not meet the IUCN distribution criteria (based on area of occupancy or extent of occurrence) for vulnerable, which require declines of at least 30% over three generations (about 15-20 years). Other IUCN distribution criteria require an area of occupancy of less than 2,000 s.km, or extent of occurrence of less than 20,000 s.km. However, these results do not provide data for assessing *P. cinereus* status against the other IUCN criteria for vulnerable, which are based on factors such as population size, rate of decline, and population modelling.

Acknowledgements

We wish to acknowledge the generous assistance of many people who provided *P. cinereus* location data for use in the analysis, in particular, Professor Jiro Kikkawa (University of Queensland), Dr David McFarland (EPA), and the staff of WildNet (EPA) including Noleen Kunst, Wayne Martin and Jan Abbotts. We also wish to acknowledge the great assistance of staff at the Queensland State Archives in providing access to valuable records in State Government correspondence, and referees for comments on the manuscript.

References

Anonymous. 1929. *The Queensland Naturalist* 7: 25.

ANZECC. 1998. *National Koala Conservation Strategy.* Environment Australia, Canberra.

Australian Koala Foundation. 2004. *Nomination for listing the koala as vulnerable.* Submission to the Commonwealth Department of the Environment and Heritage. Document on the website of the Australian Koala Foundation: http://www.savethekoala.com/vulnerable.html

Campbell, P., Prentice, R. and McRae, P. 1979. Report on the 1977 koala survey. *Wildlife in Australia* 16: 2-6.

Caughley, G. 1970. Eruption of ungulate populations, with emphasis on Himalayan thar in New Zealand. *Ecology* 51: 54-72.

Gordon, G., Brown, A.S., and Pulsford, T. 1988. A koala (*Phascolarctos cinereus* Goldfuss) population crash during drought and heatwave conditions in south-western Queensland. *Australian Journal of Ecology* 13: 451-462.

Gordon, G. and Hrdina, F. 2005. Koala and possum populations in Queensland during the harvest period, 1906-1936. *Australian Zoologist* 33: 69-99.

Gordon, G., McGreevy, D.G., and Lawrie, B.C. 1990. Koala populations in Queensland: major limiting factors. Pp 85-95 in *Biology of the Koala* (editors A.K. Lee, K.A. Handasyde, and G.D. Sanson). Surrey Beatty & Sons, Sydney.

Herbert, D.A. 1929. Letter from D.A. Herbert to Minister for Agriculture and Stock, 25th Feb 1929. *Queensland State Archives: Department of Agriculture and Stock. AGS/J565 file 29/604. 1929.*

Hrdina, F. and Gordon, G. 2004. The koala and possum trade in Queensland, 1906-1936. *Australian Zoologist* 32: 543-585.

Hume, I.D. 1990. Biological basis for the vulnerability of koalas to habitat fragmentation. Pp 32-35 in *Koala Summit. Managing koalas in New South Wales*, edited by D. Lunney, C.A. Urquhart and P. Reed. New South Wales National Parks and Wildlife Service, Sydney.

IUCN. 2001. *IUCN Red List Categories and Criteria: Version 3.1.* IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK.

Kikkawa, J. and Walter, M. 1968. Report on the koala survey, 1967. *Wildlife in Australia* 5: 100-103.

Lunney, D. and Leary, T. 1988. The impact on native mammals of land-use changes and exotic species in the Bega district, New South Wales, since settlement. *Australian Journal of Ecology* 13: 67-92.

Martin, R. and Handasyde, K. 1999. *The Koala. Natural History, Conservation and Management.* University of New South Wales Press, Sydney.

Maxwell, S., Burbidge, A.A. and Morris, K.D. 1996. *The 1996 Action Plan for Australian Marsupial and Monotremes.* Wildlife Australia, Canberra.

McAlpine, C.A., Rhodes, J.R., Callaghan, J.G., Bowen, M.E., Lunney, D., Mitchell, D.L., Pullar, D.V. and Possingham, H.P. 2006. The importance of forest area and configuration relative to local habitat factors for conserving forest mammals: A case study of koalas in Queensland, Australia. *Biological Conservation*

Melzer, A., Carrick, F., Menkhorst, P., Lunney, D. and St John, B. 2000. Overview, critical assessment, and conservation implications of koala distribution and abundance. *Conservation Biology* 14: 619-628.

Morgan, G. 2001. *Landscape health in Australia.* Environment Australia, Canberra.

Munks, S.A., Corkrey, R. and Foley, W.J. 1996. Characteristics of arboreal marsupial habitat in the semi-arid woodlands of northern Queensland. *Wildlife Research* 23: 185-195.

Pahl, L., Wylie, F.R. and Fisher, R. 1990. Koala population decline associated with loss of habitat, and suggested remedial strategies. Pp 39-47 in *Koala Summit. Managing koalas in New South Wales*, edited by D. Lunney, C.A. Urquhart and P. Reed. New South Wales National Parks and Wildlife Service, Sydney.

Patterson, R. 1996. The distribution of koalas in Queensland – 1986 to1989. Pp. 75-81 in *Koalas – Research for Management. Proceedings of the Brisbane Koala Symposium*, edited by G. Gordon. World Koala Research Incorporated, Corinda.

Phillips, S.S. 2000. Population trends and the koala conservation debate. *Conservation Biology* 14: 650-659.

Sattler, P.S. and Williams, R.D. (eds). 1999. *The Conservation Status of Queensland's Bioregional Ecosystems.* Environmental Protection Agency, Brisbane.

Seabrook, L.M., McAlpine, C.A., Phinn, S.R., Callaghan, J. and Mitchell, D. 2003. Landscape legacies: Koala habitat change in Noosa Shire, South-east Queensland. *Australian Zoologist* 32: 446-461.

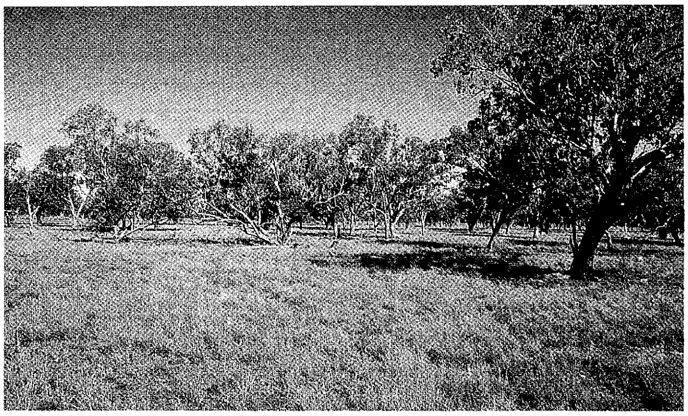
Sullivan, B.J., Baxter, G.S., Lisle, A.T., Pahl, L. and Norris, W.M. 2004. Low-density koala populations in the mulgalands of south-west Queensland. IV. Abundance and conservation status. *Wildlife Research* 31: 19-29.

White, G.C. and Garrott, R.A. 1990. *Analysis of Wildlife Radio-tracking Data.* Academic Press, San Diego.

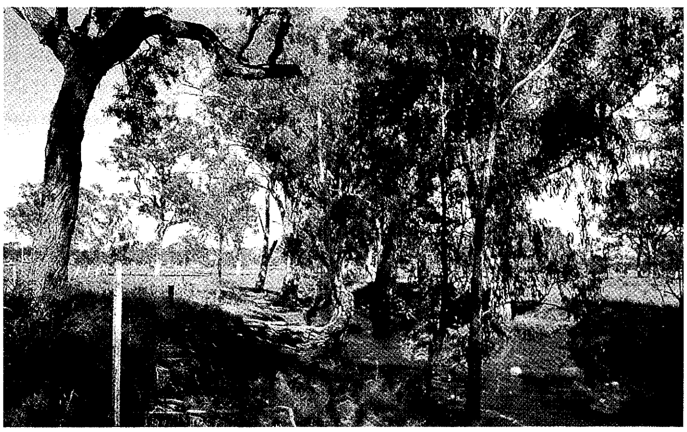
White, N.A. 1999. Ecology of the koala (*Phascolarctos cinereus*) in rural south-east Queensland, Australia. *Wildlife Research* 26: 731-744.

Wiegand, T., Revilla, E. and Moloney, K.A. 2005. Effects of Habitat Loss and Fragmentation on Population Dynamics. *Conservation Biology* 19: 108-121.

APPENDIX I



Coolibah (*Eucalyptus coolabah*) woodland, Springsure region. Koalas in this habitat reach densities of over 1 animal per hectare.



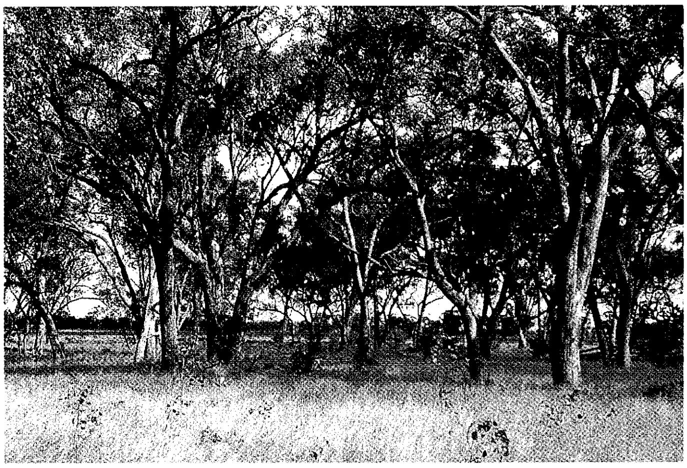
Forest red gum (*Eucalyptus tereticornis*) fringing woodland on creek, near Oakey. Koalas in this habitat reach densities of over 2 animals per hectare.

Forest red gum (*Eucalyptus tereticornis*) fringing woodland on creek, near Oakey. Koalas in this habitat reach densities of over 2 animals per hectare.

Forest red gum (*Eucalyptus tereticornis*) fringing woodland on creek, near Oakey. Koalas in this habitat reach densities of over 2 animals per hectare..

APPENDIX I

Poplar box (*Eucalyptus populnea*) woodland near Oakey. Koalas in this habitat reach densities of over 1 animal per hectare.



Poplar box (*Eucalyptus populnea*) woodland near Oakey. Koalas in this habitat reach densities of over 1 animal per hectare.

Poplar box (*Eucalyptus populnea*) woodland near Oakey. Koalas in this habitat reach densities of over 1 animal per hectare.

Popular box (*Eucalyptus populnea*) woodland near Oakey. Koalas in this habitat reach densities of over 1 animal per hectare.

APPENDIX I

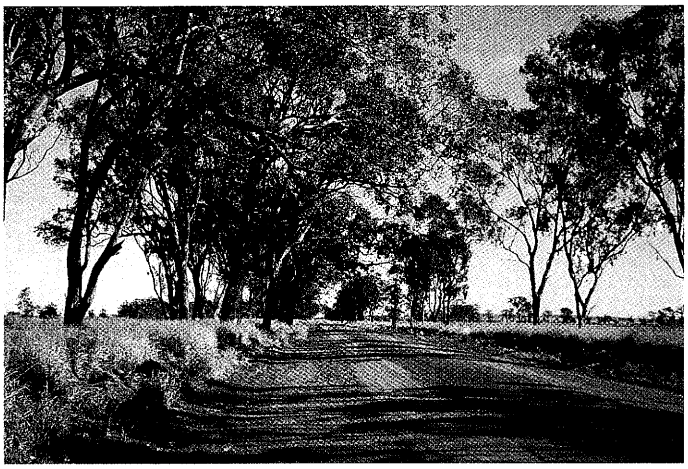
Koala in poplar box (*Eucalyptus populnea*) near Oakey.

River red gum (*Eucalyptus camaldulensis*) fringing woodland on dry stretch of creek in western Queensland. Koalas in this habitat may reach densities of about 0.5 animals per hectare.

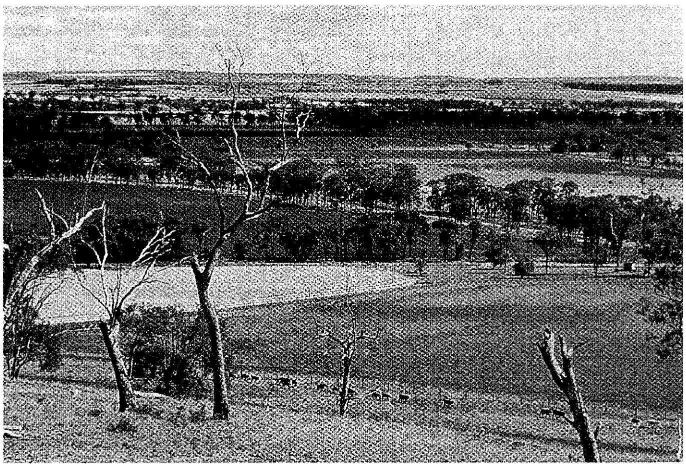
River red gum (*Eucalyptus camaldulensis*) fringing woodland on waterhole in creek in western Queensland. Koalas in this habitat reach densities of over 2 animals per hectare.

River red gum (*Eucalyptus camaldulensis*) fringing woodland on dry stretch of creek in western Queensland. Koalas in this habitat may reach densities of about 0.5 animals per hectare.

APPENDIX I



Roadside strips of poplar box (*Eucalyptus populnea*) woodland near Oakey.



Roadside strips of poplar box (*Eucalyptus populnea*) woodland near Oakey. Koalas in this habitat reach densities of over 1 animal per hectare.

Roadside strips of poplar box (*Eucalyptus populnea*) open woodland near Oakey.

Roadside strips of poplar box (*Eucalyptus populnea*) open woodland near Oakey.

APPENDIX I

Roadside strips of poplar box (*Eucalyptus populnea*) woodland near Oakey. Koalas in this habitat reach densities of over 1 animal per hectare.

Roadside strips of poplar box (*Eucalyptus populnea*) woodland near Oakey. Koalas in this habitat reach densities of over 1 animal per hectare.