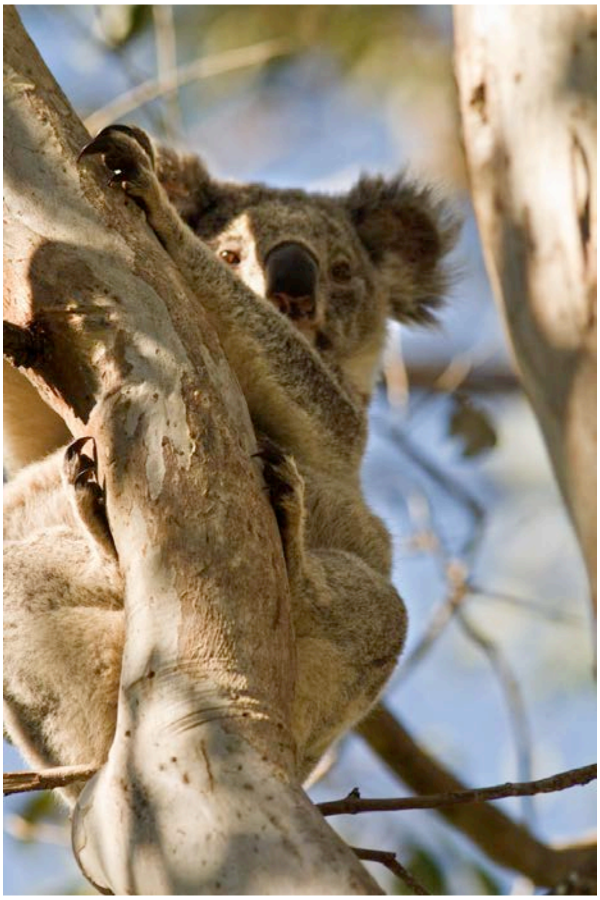

A Preliminary Map of the Likelihood of Koala Occurrence in NSW

For use in Private Native Forestry applications

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Cover photograph: Koala in forest red gum *Eucalyptus tereticornis* – Coffs Harbour NSW - John Turbill/OEH

Contents

1. Introduction 1

1.1 Private Native Forestry in New South Wales 1

1.2 Aims of this project 3

2. Map preparation 4

2.1 The model of koala distribution used 4

2.2 The data used and its limitations 5

2.3 Measuring the confidence associated with the likelihood values 6

3. Koala likelihood map 9

3.1 The state picture 9

3.2 Koala Management Area 1 – North Coast 11

3.3 Koala Management Area 2 – Central Coast 13

3.4 Koala Management Area 3 – South Coast 14

3.5 Koala Management Area 4 – Northern Tablelands 14

3.6 Koala Management Area 5 – Central & Southern Tablelands 14

3.7 Koala Management Area 6 – Western Slopes and Plains 16

3.8 Koala Management Area 7 – Far West and South West 17

4. How to use the map 19

4.1 Step1: Determine the *p* value (likelihood of koalas) for the cell that covers the area of interest. 19

4.2 Step 2: Determine the confidence for the target cell 19

4.3 Step 3: Determine the action level for the target cell 20

4.4 Step 4: Apply the Action Level to the patch of vegetation 21

4.5 Special case 21

5. Future refinements of the map 22

6. References 23

Appendix 1: Distribution models considered 25

Appendix 2: Map metadata 28

List of figures

Figure 1: The distribution of PNF PVPs in NSW between 2007 and 2013. 2

Figure 2: 10 km grid used for the Koala likelihood estimate. 4

Figure 3: Distribution of koala (a) and 'other species' (b) records (1994 to 2014). 6

Figure 4: The distribution of C_{max} against *p* for *N* values corresponding to the cut-off values in KMAs 1-7 at 10 km^2. 8

Figure 5: The state-wide distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate. 10

Figure 6: The distribution of (a & b) the likelihood of koalas (*p*) and (c & d) the confidence level in the estimate within KMA 1. Data are shown at a 10 km (a &c) and 5 km (b & d) grid cell resolution. 12

Figure 7: The distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate within KMA 2. 13

Figure 8: The distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate within KMA 3. 14

Figure 9: The distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate within KMA 4. 16

Figure 10: The distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate within KMA 5. 16

Figure 11: The distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate within KMA 6. 17

Figure 12: The distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate within KMA 7. 18

Figure 13: A constructed example of PNF properties and the koala likelihood map. 19

Figure A1.1: The frequency of koala records (1994–2014) within a 10 km^2 grid. 25

List of tables

Table 1: Cut-off values for the categorisation of the confidence levels of the likelihood estimate. 7

Table 2: Numbers of records corresponding with the cut-off values. 7

Table 3: Data fields included in the preliminary map of the likelihood of koala occurrence in NSW. 9

Table 4: The number (and percentage) of cells with each estimate of the likelihood of koalas (*p*). Colours correspond approximately with the categories used in the maps in the report. 11

Table 5: The number (and percentage) of cells within each confidence category. Colours correspond with the categories used in the maps in the report. 11

Table 6: Rules to apply based on the confidence category. 20

Table 7: Prescription levels based on p-values and KMA (completed only for KMA1 and 3). 20

1. Introduction

The NSW Environment Protection Authority (EPA) is currently considering options to better integrate current and future koala distribution and habitat mapping with regulation of Private Native Forestry (PNF), to ensure consistency and improved protection for koala habitat (EPA 2013). The EPA engaged the Office of the Environment and Heritage (OEH) to prepare a baseline map of koala distribution presented in this report.

Within NSW, the koala (*Phascolarctos cinereus*) is listed as Vulnerable under the *Threatened Species Conservation Act 1995* and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. While formerly widespread in NSW, remaining populations of koalas are concentrated on the north, mid-north and central coasts, and west of the divide in the northern part of the state. Small and isolated populations also occur in other parts of the state.

The NSW Recovery Plan for the koala (Department of Environment and Climate Change [DECC] 2008) recognises a number of threats for the species, a key one being the loss of habitat and habitat fragmentation. Other threats include road kills, dog attacks, fire, disease, severe weather and climate change.

The Recovery Plan indicates that the threat posed to Koalas from logging regimes requires further investigation. It does however note that PNF may pose a threat to koalas in some parts of NSW, particularly on the north coast, where there is selective logging of primary koala food trees, in particular tallowwood, forest red gum and grey gum (DECC 2008).

1.1 Private Native Forestry in New South Wales

PNF is the sustainable logging of native vegetation on privately owned lands. Harvesting of timber as part of PNF requires approval through a PNF Property Vegetation Plan (PNF PVP) that aims for improved or maintained environmental outcomes. A PNF PVP is a legally binding agreement between a landholder and the EPA. The PNF Code of Practice (DECC 2008a) sets the minimum environmental standards for harvesting in private native forests.

PNF PVPs are not distributed evenly across the state (Figure 1), with the majority in the north coast, where koala population centers occur. Between 2007 and 2013, 2501 PNF PVPs were approved, covering a total area of 479,392 hectares (EPA 2014).

In addition to protection of general landscape features such as forested riparian areas, wetlands, rocky outcrops, rainforest, steep lands and old-growth forests, the PNF Code of Practice includes additional protective measures for some threatened species, including the koala. The code includes additional protections where there is a known record or site evidence of koalas. These additional provisions are contained in the Listed Species Ecological Prescriptions section of the code (DECC 2008a).

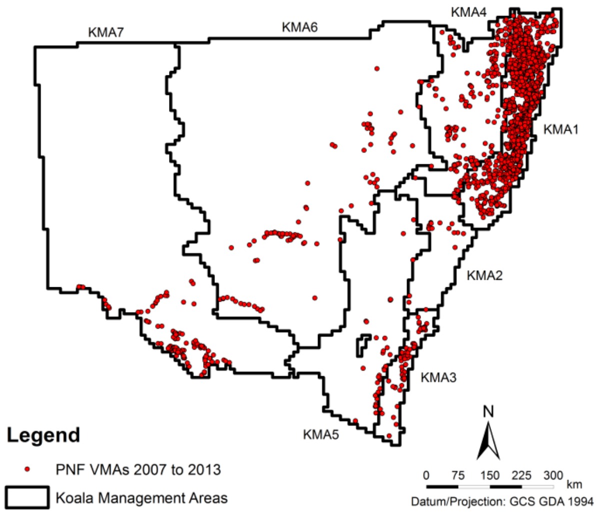


Figure 1: The distribution of PNF PVPs in NSW between 2007 and 2013 (VMA in the map should be taken to read 'approved PVPs').

The specific provisions for the koala are:

- Forest operations are not permitted within any area identified as core koala habitat within the meaning of State Environmental Planning Policy 44 – Koala Habitat Protection (SEPP 44). Under SEPP 44 core koala habitat is defined as 'an area of land with a resident population of koalas, evidenced by attributes such as breeding females (that is, females with young) and recent sightings of and historical records of a population'.
- Any tree containing a koala, or any tree beneath which 20 or more koala faecal pellets (scats) are found must be retained, and an exclusion zone of 20 metres must be implemented around each retained tree.
- Where there is a record of a koala within an area of forest operations or within 500 metres of an area of forest operations or a koala faecal pellet (scat) is found beneath the canopy of any primary or secondary koala food tree, the following must apply:
  - a minimum of 10 primary koala food trees and five secondary koala food trees must be retained per hectare of net harvesting area (not including other exclusion or buffer zones), where available
  - these trees should preferably be spread evenly across the net harvesting area, have leafy, broad crowns and be in a range of size classes with a minimum of 30 centimetres diameter at breast height over bark
  - damage to retained trees must be minimised by directional felling techniques.
  - post-harvest burns must minimise damage to the trunks and foliage of retained trees.

These above measures are triggered by either the existence of koala records in the *Atlas of NSW Wildlife* (OEH 2014a) or identification of the presence of koalas (or evidence of their presence) by the landholder and/or a logging operator. The PNF Code of Practice does not require pre-logging surveys for koalas.

Core koala habitat as defined under SEPP 44 has not been mapped consistently across the state and there is often misapplication of its definition within PNF applications. Further, the *Atlas of NSW Wildlife* does not provide a consistent survey for koalas across the state. As a result, the provisions for koalas in the PNF Code of Practice are often not triggered or are not consistently applied (OEH).

1.2 Aims of this project

This project aims to create a map of koala occurrence across NSW using currently available data on where koalas occur (e.g. *Atlas of NSW Wildlife*). This map is seen as the first stage of a broader project aimed at mapping habitat of koalas for integration with regulation of PNF, although the map produced here is not a habitat map. The map must use a consistent mapping method across the state, while at the same time allow for known variation in koala habitat (e.g. differences in Koala Management Areas [KMAs]). The project aims to identify gaps in our knowledge of koala distribution as reflected in the map so that priorities can be set for future data gathering. The scope for the project indicated that vegetation mapping is not intended to be used in the baseline mapping sub-project, although future refinement projects will need to incorporate this.

The project is split into two stages:

- Stage 1: Development of a state-wide baseline map of koala distribution in NSW as well as the development of a series of regional maps. The resultant maps will identify areas of NSW as:
    - highly significant
    - low to moderate significance
    - koalas not known to occur or occur at very low densities.
- Stage 2: Comparison of the developed baseline map(s) with currently available koala habitat mapping with a discussion on any discrepancies between the maps.

This report presents the results of Stage 1 (map development). Stage 2 results are presented in a separate report (OEH 2014b).

2. Map preparation

2.1 The model of koala distribution used

The model used in preparing the koala distribution map is: the number of koala records within a set area relative to the number of records of a suite of other mammals (i.e. the likelihood of koala occurrence). The records of other mammals provide a measure of survey effort independent of koalas and allow identification of areas where survey has taken place but koalas have not been recorded. A range of different models was considered (Appendix 1), but the simple proportion of koalas within a broader set of records was considered to best represent the distribution of koalas given the restrictions of the data and the broad aims of the project.

The state of NSW was covered by a 10 kilometre by10 kilometre grid that encloses the state entirely (Figure 2). This spatial scale is the same as that used in previous state-wide modelling of the distribution of koalas (Lunney *et al.* 2009) and at this scale, previous studies of koala distribution indicate that the effects of spatial autocorrelation are minimal at distances greater than 8 kilometre (McAlpine *et al.* 2006a, 2006b). The state was further split into KMAs as per the NSW Koala Recovery Plan (DECC 2008) with the KMA boundaries adjusted to align with the 10 kilometre^2 grid (Figure 2). Following an initial inspection of the data, and given the high number of records in KMA1 (North Coast), a 5 kilometre by 5 kilometre grid was additionally used for KMA1. Despite valid reasons for initially choosing a 10 kilometre^2 grid (see above), it was felt that the potential problems of spatial autocorrelation could be relaxed in a management situation, such as the preparation of a distribution map.

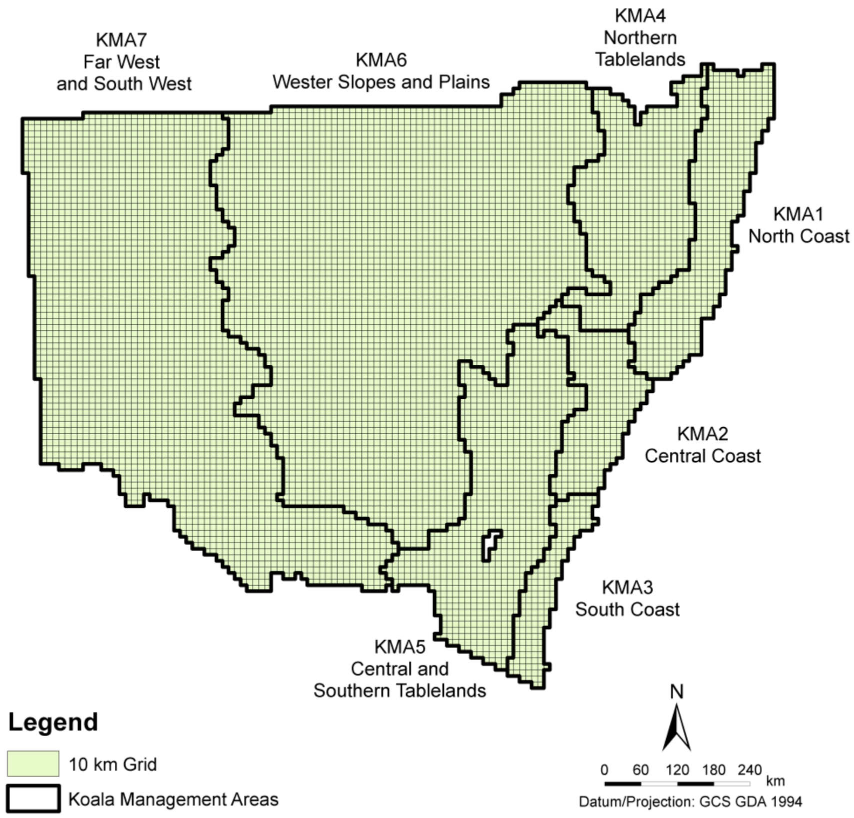


Figure 2: 10 km grid used for the Koala likelihood estimate.

The likelihood of koalas (p) was calculated for each grid cell based on a binomial distribution with each record (koala (K) or other mammal) being either a koala or another mammal. The proportion of all records within a cell (N) (all subject species including koalas) in a grid cell that are koalas represents the likelihood (Equation 1).

$$p = K/N \qquad \text{(Eq. 1)}$$

This provides the likelihood of koalas being recorded, with a value between 0 and 1. This method is similar to that used for bats (Pennay *et al*., 2011), although there is not a single uniform taxonomic group to use, as is the case with bats, and a selection of mammals has been used to provide the background data (refer Section 2.2).

2.2 The data used and its limitations

Data were obtained from the *Atlas of NSW Wildlife* (OEH 2014a) for the entire state. The atlas includes records of koalas (and other species) obtained as part of the 2006 NSW Community Wildlife Survey (Lunney *et al.* 2009) and these represent nearly 13% of the koala records for the period of interest (1994 to 2014). In addition to records of koalas, records of a suite of 'other' species of mammal were obtained in order to provide background data on survey effort and to identify areas where survey has taken place but no koalas have been recorded.

The 'other' species group included all species in the following taxonomic groups:

- Family: *Tachyglossidae*
- Family: *Vombatidae*
- Family: *Petauridae*
- Family: *Pseudocheiridae*
- Family: *Phalangeridae*
- Family: *Macropodidae*
- Family: *Canidae*
- Genus: *Dasyurus*.

The group included a total of 48 'other' species. This group includes most of the species of mammals included in this survey (Lunney *et al.* 2009) including brushtail possum, echidna, spotted-tail quoll, wombat, wild dog/dingo and fox. As with the koala, records from the survey make up a significant proportion (21%) of the records for the period of interest.

Records for both groups (koalas and 'other' species) were restricted to the last 20 years (1994 to 2014), representing approximately three generations of koalas. This corresponds with the three generations used in the International Union for Conservation of Nature (IUCN) red book criteria to determine a decline in a species (IUCN, 2001).

Records within the atlas include a spatial accuracy field. Records with a spatial accuracy value greater than 10 kilometre were removed from the dataset.

This resulted in 23,386 records of koalas and 162,325 records of 'other' species (Figure 3).

The Geospatial Modelling Environment (Beyer 2012) was used to count the number of records of koalas (K) and total records (N) within each grid cell.

2.3 Measuring the confidence associated with the likelihood values

We represented the confidence in the likelihood value (*p*) by calculating the exact binomial confidence interval (Blyth 1986; Morisette and Siamak 1998):

$$\frac{1}{1+\frac{N-K+1}{K}F_{2(N-K+1),2K,\alpha/2}} \leq p \leq \frac{\frac{K+1}{N-K}F_{2(K+1),2(N-K),\alpha/2}}{1+\frac{K+1}{N-K}F_{2(K+1),2(N-K),\alpha/2}} \quad \text{(Eq. 2)}$$

Where $F_{v1,v2,alpha}$ is the upper 100 x (1-alpha)th percentile from an *F* distribution with *v1* and *v2* degrees of freedom. In this case we used the 95% confidence interval and alpha = 0.05. In cases where *K* = 0 (i.e. no koalas were sighted), the lower confidence limit cannot be resolved and we set the lower confidence limit to 0. Similarly, in cases where N-K = 0 (i.e. only koalas were sighted within the grid), the upper confidence cannot be resolved and we set the upper confidence limit to 1.

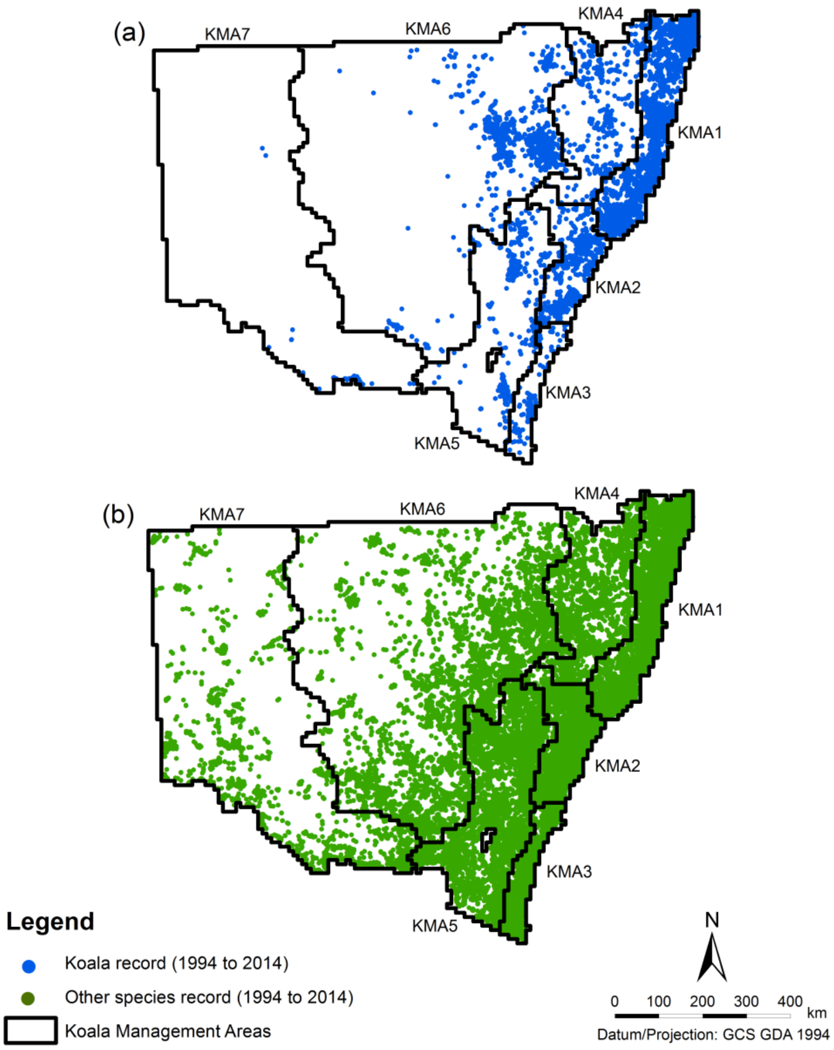


Figure 3: Distribution of koala (a) and 'other species' (b) records (1994 to 2014).

In order to allow comparison of the confidence among grid cells, the larger value (C_{max}) of two arms of the 95% confidence interval (C_{U95} and C_{L95}) was used:

$$C_{max} = Max\,((p - C_{L95}), (C_{U95} - p)) \qquad \text{(Eq. 3)}$$

Although the standard deviation of an estimate is more commonly used (Sokal and Rohlf, 1995) for comparison of values, it suffers the problem of not showing variation when $K = 0$ or when $K = N$, regardless of the value of N. That is, the standard deviation when $p = 0$ or 1 is always 0, regardless of value of N.

The Maximum Confidence (C_{max}) was assigned to one of three categories (high, moderate or low confidence) based on the cut-off values presented in Table 1. These values were chosen with reference to the distribution of the three categories and also with reference to the values of N (the total number of records per grid cell) that correspond approximately with the cut-off values as shown in Table 2.

Table 1: Cut-off values for the categorisation of the confidence levels of the likelihood estimate.

KMA	A – High Confidence	B – Moderate Confidence	C – Low confidence
1-7 (10 km²)	$C_{max} \leq 0.1$	$0.1 < C_{max} \leq 0.2$	$C_{max} > 0.2$
1 (5 km²)	$C_{max} \leq 0.2$	$0.2 < C_{max} \leq 0.3$	$C_{max} > 0.3$

Table 2: Numbers of records corresponding with the cut-off values.

KMA	A – High Confidence	B – Moderate Confidence	C – Low confidence
1-7 (10 km²)	$N > 110$ $N > 36$ at $p = 0$ or $p = 1$	$N > 29$ $N > 17$ at $p = 0$ or $p = 1$	$N < 29$ $N < 17$ at $p = 0$ or $p = 1$
1 (5 km²)	$N > 30$ $N > 17$ at $p = 0$ or $p = 1$	$N > 14$ $N > 11$ at $p = 0$ or $p = 1$	$N < 14$ $N < 11$ at $p = 0$ or $p = 1$

The distribution of C_{max} is not linear when N is kept constant and considering all possible values of p (Figure 4), with higher confidence (i.e. lower values of C_{max}) when p approaches 0 or 1). Therefore two values of N are provided in Table 2 corresponding with the cut-off values: The value of N at which C_{max} is less than the cut-off value regardless of the estimate of p (e.g. $N > 120$ for the high confidence cut-off); the value of N where only C_{max} for $p = 0$ or 1 is equal to the cut-off value (e.g. $N = 36$ for the high confidence cut-off). This means that for the high confidence cut-off value for the 10 kilometre^2 grid ($C_{max} \leq 0.1$):

- cells with less than 36 records ($N < 36$) will not have high confidence, regardless of the estimate of p
- cells with greater than 120 records ($N > 120$) will have high confidence regardless of the value of p
- cells with records between 36 and 120, will only have high confidence depending on the value of p.

For each estimate of *p* we also calculated a one-sided 95% confidence limit:

$$0 \leq p \leq \frac{\frac{K+1}{N-K}F_{2(K+1),2(N-K),\alpha}}{1+\frac{K+1}{N-K}F_{2(K+1),2(N-K),\alpha}} \quad \text{(Eq. 4)}$$

This provides a more realistic measure of the upper confidence limit given that all of alpha value (i.e. 5%) is attributed to the upper limit. This is a better representation given that the map and the estimates of *p* may be used for management purposes.

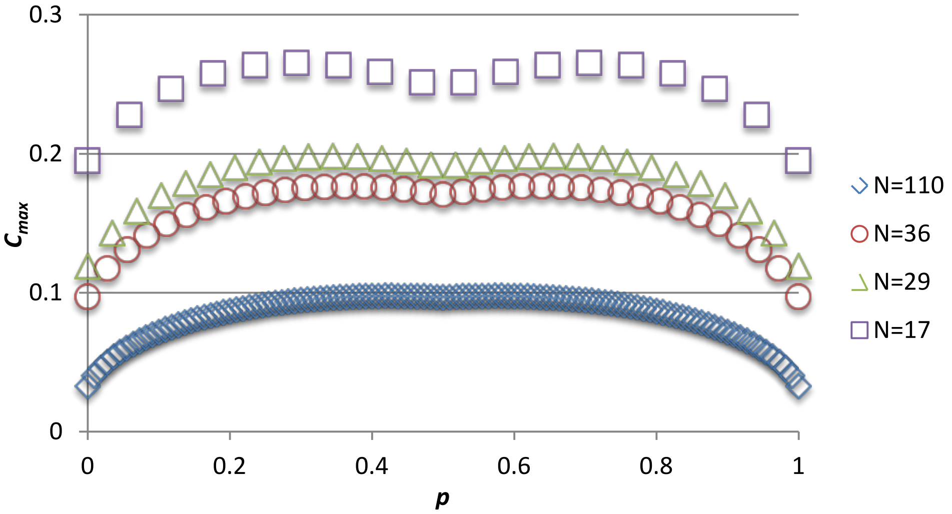


Figure 4: The distribution of C_{max} against *p* for *N* values corresponding to the cut-off values in KMAs 1-7 at 10 km^2.

3. Koala likelihood map

The preliminary map of the likelihood of koala occurrence in NSW is presented as two ArcGIS Shapefiles:

- Koala_Likelihood_Map_10 km.shp – this presents the data based on a 10 kilometre^2 grid for all of NSW covering KMAs 1 to 7
- Koala_Likelihood_Map_10 km_and_5 km.shp – this presents the data based on a 10 kilometre^2 grid for KMAs 2-7 and on a 5 kilometre^2 grid for KMA 1 (North Coast).

Both shapefiles include a number of data fields as shown in Table 3.

Table 3: Data fields included in the preliminary map of the likelihood of koala occurrence in NSW.

Field	Explanation	Comment
Grid	A unique identifying number for each grid cell	
KMA	Koala Management Area	The boundaries of the KMAs were adjusted to coincide with the 10 km grid so that each grid covered only one KMA.
Koalas_K	The number of koala records within the grid cell (*K*)	
Surveys_N	The total number of records (Koalas and Other Species) within the grid cell (*N*)	
p	The likelihood of koala occurrence within the grid cell (*p*)	Grid cells with no surveys (N=0) (i.e. No Data) have a value of '999'.
Lower_95	The lower 95% confidence interval associated with the estimate of the likelihood of koalas within the grid cell (C_{L95})	
Upper_95	The upper 95% confidence interval associated with the estimate of the likelihood of koalas within the grid cell (C_{U95})	
CI	The 95% confidence interval (C_{U95} - C_{L95})	
Cmax	The value of the larger of two arms of the confidence interval (C_{max})	
U95_1Sided	The value of the upper 95% confidence interval using a one-sided confidence interval	
Confidence	The confidence category assigned to the grid cell estimate based on the cut-off values shown in Table 1	

Metadata associated with the map are presented in Appendix 2.

3.1 The state picture

The picture for the likelihood of koalas across the state (Figure 5a) fits with the expected general pattern. There is a higher likelihood of koalas occurring on the north coast (KMA1). Hot spots with higher likelihood of koalas, such as Coffs Harbour and Bellingen Local Government Areas (LGAs) in the mid north coast, are clearly identifiable. Other clear hot spots occur in KMA6 (Western Slopes and Plains) within and surrounding the Pilliga Forests and Gunnedah. The general distribution of the likelihood of occurrence of koalas fits with earlier published distributions such as those based on the 2006 state-wide community survey (DECC 2008; Lunney *et al.* 2009).

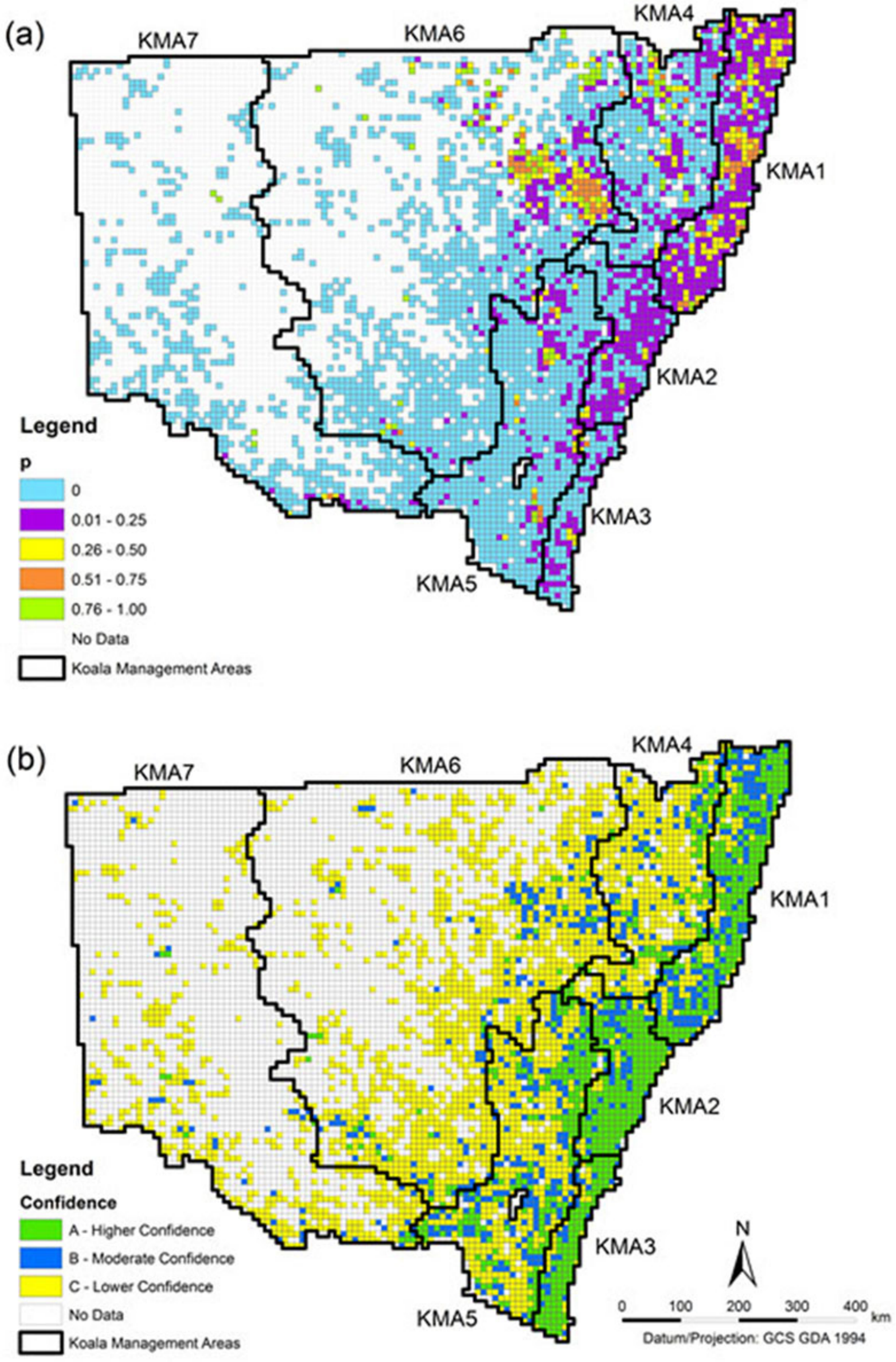


Figure 5: The state-wide distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate.

Forty-eight percent of the cells contain No Data (Figure 5a and Table 4), although these occur largely in KMA6 and KMA7 (Far West and South West). Cell with higher confidence in the likelihood estimate occur mainly in the coastal KMAs with generally decreasing confidence moving from east to west (Figure 5b and Table 5). Only 11% of cells across the state were assigned to the high confidence category, 8% to the moderate category and 33% to the low category (Table 5). Some cells that sit across the state border or along the coast have low likelihood values (or No Data) because only a small proportion of the cell area sits within NSW and hence number of records may be low or non-existent.

Table 4: The number (and percentage) of cells with each estimate of the likelihood of koalas (*p*). Colours correspond approximately with the categories used in the maps in the report.

p	Koala Management Area (KMA) at 10 km								KMA1 (5 km)
	1	2	3	4	5	6	7	State	
0	73 (14.5%)	133 (43.3%)	106 (62.4%)	342 (55.0%)	631 (74.8%)	1151 (34.6%)	539 (21.4%)	2975 (35.9%)	589 (30.5%)
0.1	129 (25.6%)	127 (41.4%)	45 (26.5%)	92 (14.8%)	95 (11.3%)	44 (0.3%)	6 (0.2%)	538 (0.5%)	254 (13.2%)
0.2	101 (20.1%)	28 (0.1%)	7 (0.1%)	49 (0.9%)	25 (0.0%)	58 (0.7%)	3 (0.1%)	271 (0.3%)	269 (13.9%)
0.3	70 (13.9%)	6 (0.0%)	2 (0.2%)	15 (0.4%)	13 (0.5%)	42 (0.3%)	4 (0.2%)	152 (0.8%)	177 (0.2%)
0.4	43 (0.5%)	2 (0.7%)	1 (0.6%)	15 (0.4%)	8 (0.9%)	20 (0.6%)	1 (0.0%)	90 (0.1%)	121 (0.3%)
0.5	26 (0.2%)	2 (0.7%)	3 (0.8%)	12 (0.9%)	6 (0.7%)	37 (0.1%)	1 (0.0%)	87 (0.0%)	93 (0.8%)
0.6	17 (0.4%)	(0.0%)	1 (0.6%)	1 (0.2%)	2 (0.2%)	18 (0.5%)	1 (0.0%)	40 (0.5%)	50 (0.6%)
0.7	13 (0.6%)	1 (0.3%)	0 (0.0%)	4 (0.6%)	4 (0.5%)	15 (0.5%)	0 (0.0%)	37 (0.4%)	52 (0.7%)
0.8	11 (0.2%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	3 (0.4%)	8 (0.2%)	0 (0.0%)	22 (0.3%)	25 (0.3%)
0.9	4 (0.8%)	1 (0.3%)	0 (0.0%)	0 (0.0%)	3 (0.4%)	7 (0.2%)	0 (0.0%)	15 (0.2%)	18 (0.9%)
1	5 (0.0%)	(0.0%)	1 (0.6%)	19 (0.1%)	2 (0.2%)	44 (0.3%)	4 (0.2%)	75 (0.9%)	31 (0.6%)
No Data	11 (0.2%)	7 (0.3%)	4 (0.4%)	73 (11.7%)	52 (0.2%)	1878 (56.5%)	1963 (77.8%)	3988 (48.1%)	251 (13.0%)
Total	**503**	**307**	**170**	**622**	**844**	**3322**	**2522**	**8290**	**1930**

Table 5: The number (and percentage) of cells within each confidence category. Colours correspond with the categories used in the maps in the report.

Confidence	**Koala Management Area at 10 km**								**KMA1 (5km)**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**State**	
A	259 (51.5%)	209 (68.1%)	115 (67.6%)	81 (13.0%)	197 (23.3%)	44 (1.3%)	12 (0.5%)	917 (11.1%)	706 (36.6%)
B	149 (29.6%)	52 (16.9%)	24 (14.1%)	92 (14.8%)	180 (21.3%)	134 (4.0%)	40 (1.6%)	671 (8.1%)	290 (15.0%)
C	84 (16.7%)	39 (12.7%)	27 (15.9%)	376 (60.5%)	415 (49.2%)	1266 (38.1%)	507 (20.1%)	2714 (32.7%)	683 (35.4%)
No Data	11 (2.2%)	7 (2.3%)	4 (2.4%)	73 (11.7%)	52 (6.2%)	1878 (56.5%)	1963 (77.8%)	3988 (48.1%)	251 (13.0%)
Total	**503**	**307**	**170**	**622**	**844**	**3322**	**2522**	**8290**	**1930**

3.2 Koala Management Area 1 – North Coast

A detailed assessment of how the current map compares with existing koala habitat mapping within KMA1, such as from Comprehensive Koala Plans of Management for the north coast, is presented in a separate accompanying report (OEH 2014b). The Stage 2 report indicates overall broad agreement between koala likelihood of occurrence mapping and the locally derived koala habitat mapping. It states that given the inherent differences between the two mapping methods it would be unrealistic to expect perfect concurrence. Below is a more general discussion of the mapping results for KMA1.

The maps of the likelihood of koalas at both 10 kilometre (Figure 6a) and 5 kilometre (Figure 6b) scales show that koalas are widely distributed across KMA1. Known hot-spots are clearly identifiable such as Coffs Harbour in the mid north coast (Lunney *et al*. 1999) and Lismore in the north (Biolink Ecological Consultants 2011).

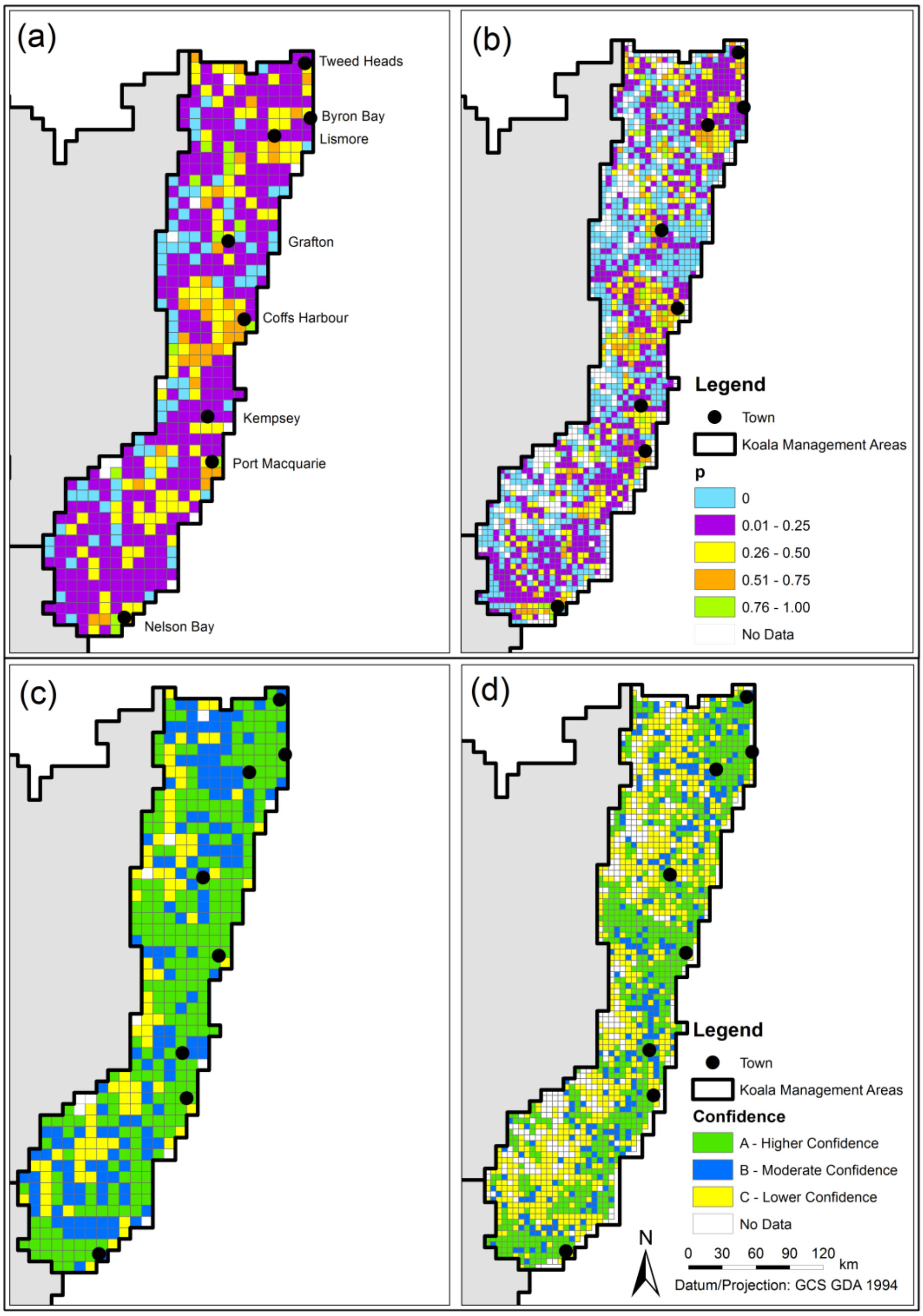


Figure 6: The distribution of (a & b) the likelihood of koalas (*p*) and (c & d) the confidence level in the estimate within KMA 1. Data are shown at a 10 km (a &c) and 5 km (b & d) grid cell resolution.

Overall the confidence in the likelihood estimates is high throughout the management area (Figure 6c and 6d). As would be expected, the finer-scale grid (Figure 6b and 6d) contains a higher percentage of cells with No Data or Lower Confidence than the 10 kilometre^2 cells

(48.4% versus 18.9%, see Table 5). These cells tend to occur towards the west of the KMA on the Great Dividing Range, where survey, and hence the number of records, is low.

3.3 Koala Management Area 2 – Central Coast

The likelihood of koalas within KMA2 is generally low but spread widely, including in the Hunter north of Sydney and the south (Figure 7a). A higher probability occurs at Campbelltown, between Sydney and Wollongong, corresponding with a known population centre (Australian Koala Foundation and Campbelltown City Council 2005; Lunney *et al*. 2010).

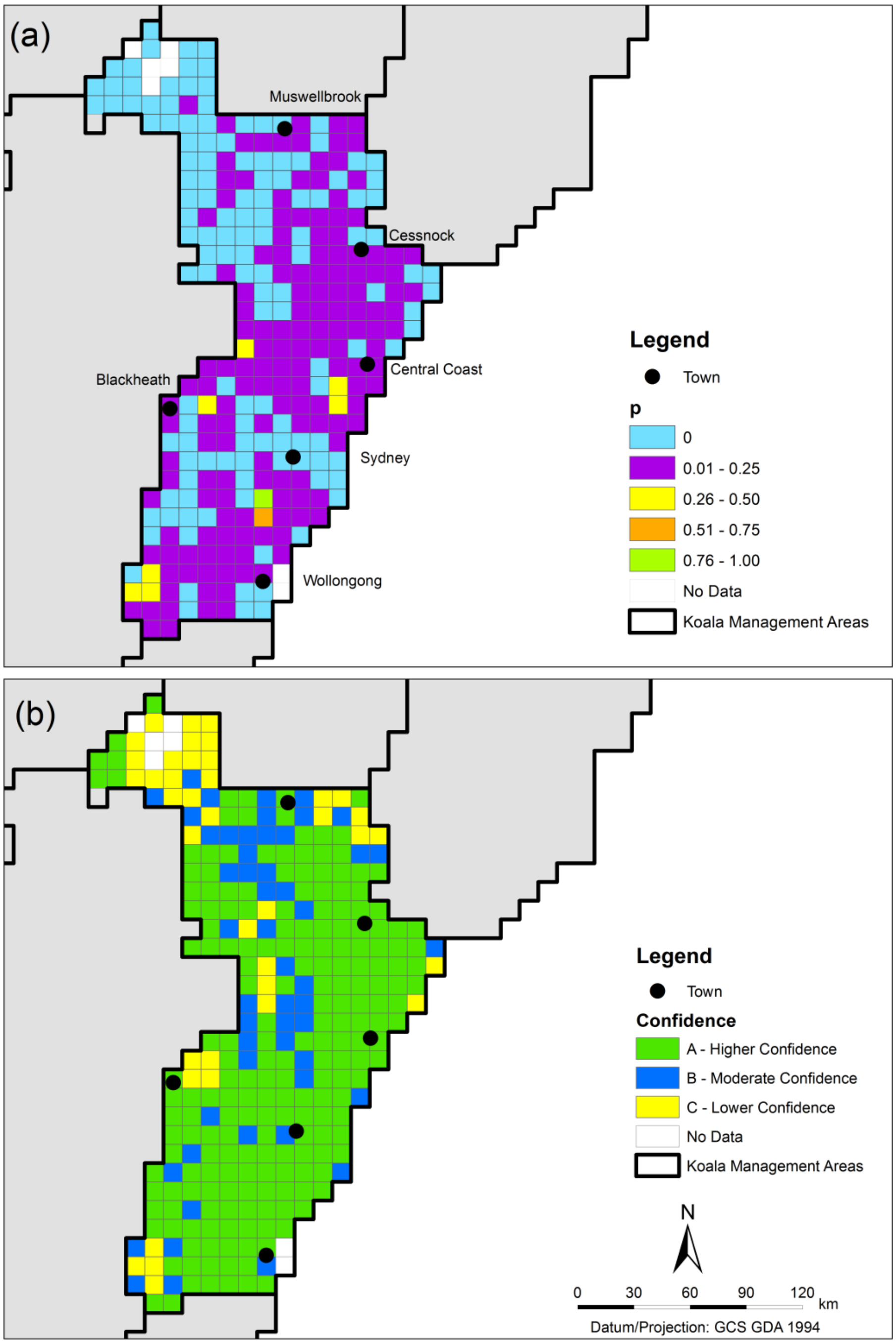


Figure 7: The distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate within KMA 2.

Overall a high percentage of cells (68%) have been assigned to the High Confidence category (Table 5). Only seven cells (2.3%) have No Data recorded.

3.4 Koala Management Area 3 – South Coast

The likelihood of koalas is generally very low and patchy across KMA3 (South Coast) (Figure 8a). There is a higher likelihood of koalas in the north of Eden LGA north of Bega (Figure 8a), corresponding with a known refuge of koalas (Lunney *et al*. 2014). Generally a high percentage of cells are assigned to the High Confidence category (68%, see Table 5 and Figure 8b). Only four cells (2.4%) contain No Data.

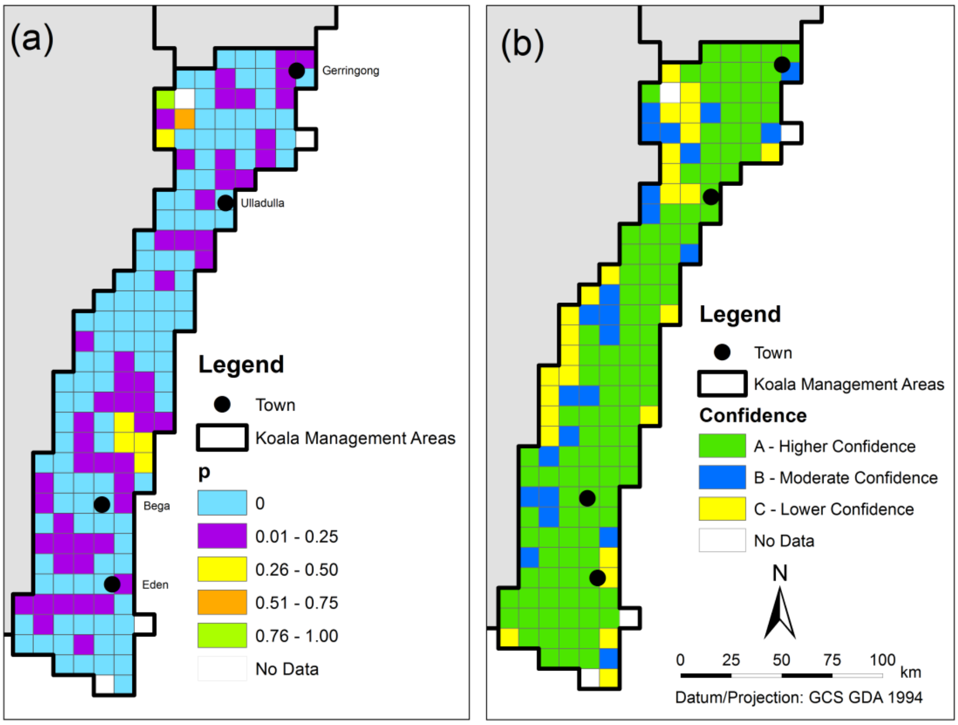


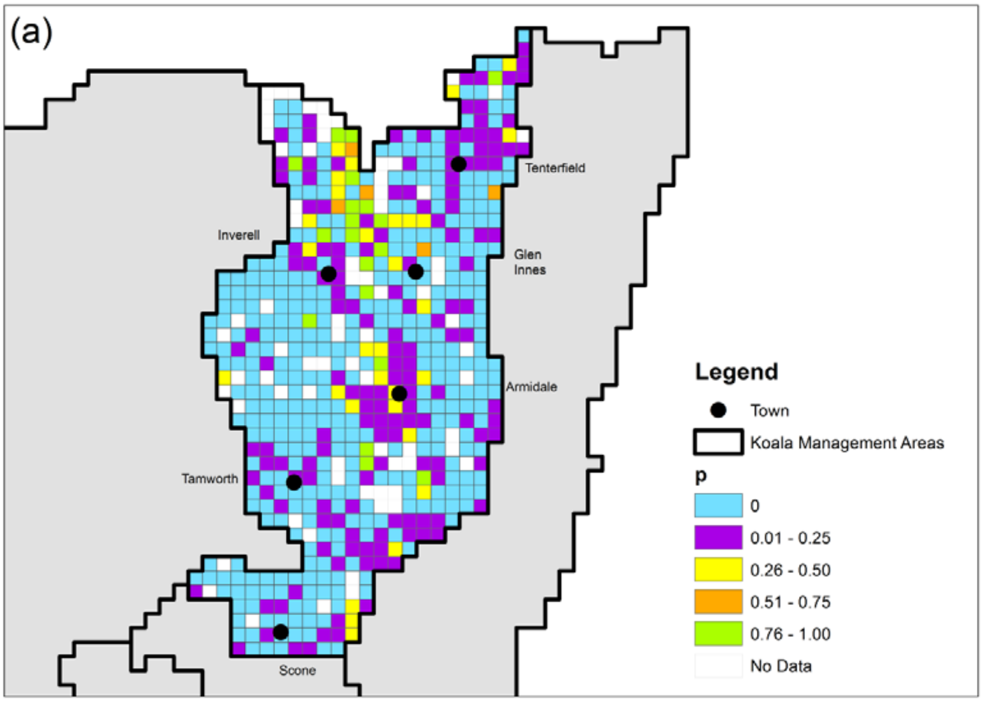
Figure 8: The distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate within KMA 3.

3.5 Koala Management Area 4 – Northern Tablelands

The NSW Koala Recovery Plan (DECC 2008) indicates that while there are records scattered throughout the KMA the distribution of koalas remains unclear. This pattern is reflected in the current map where generally there is very low likelihood of koalas throughout the KMA (Figure 9a). There does appear to be higher likelihood of koalas to the north-west of Glenn Innes, but estimates in this area are assigned low confidence (Figure 9b).

3.6 Koala Management Area 5 – Central & Southern Tablelands

The likelihood map for koalas (Figure 10a) suggests koalas do not exist or are in very low densities across much of the KMA, although the confidence in the results are generally low (Figure 10b). The likelihood estimates do pick up the known population of koalas to the north-east of Cooma on the Monaro Tablelands (Figure 10a) (Allen 1999) and a population at Bathurst (DECC 2008). Only 23% of the grid cells are assigned to the high confidence category (Figure 10b and Table 5). Six percent of the grid cells have No Data (Table 5).


(a)
Tenterfield
Inverell
Glen Innes
Armidale
Tamworth
Scone
Legend
Town
Koala Management Areas
p
0
0.01 - 0.25
0.26 - 0.50
0.51 - 0.75
0.76 - 1.00
No Data

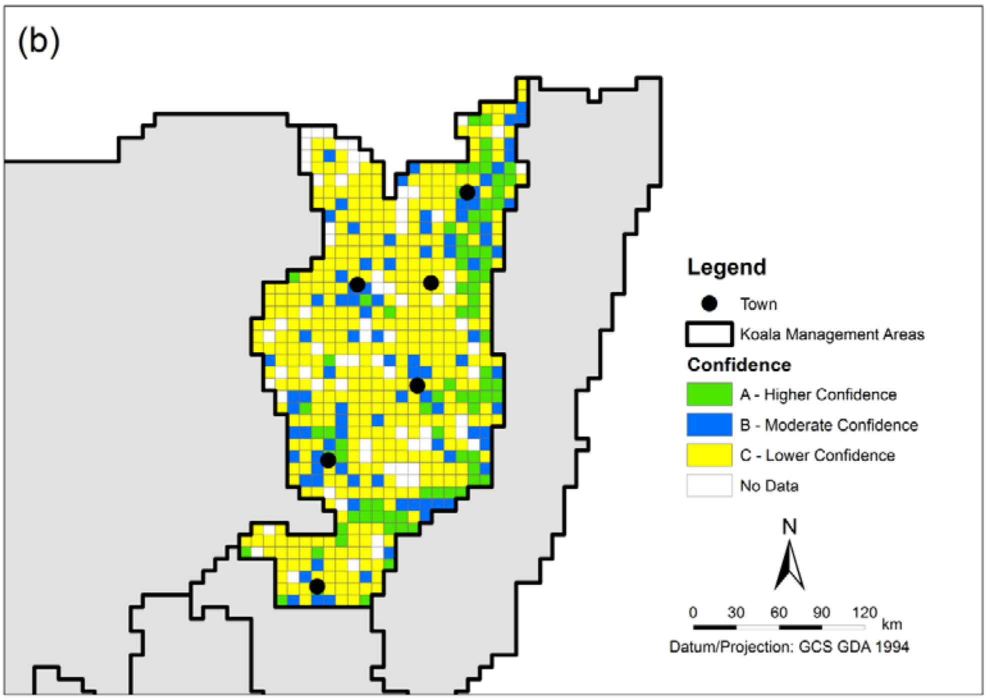

(b)
Legend
Town
Koala Management Areas
Confidence
A - Higher Confidence
B - Moderate Confidence
C - Lower Confidence
No Data
N
0 30 60 90 120 km
Datum/Projection: GCS GDA 1994

Figure 9: The distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate within KMA 4.

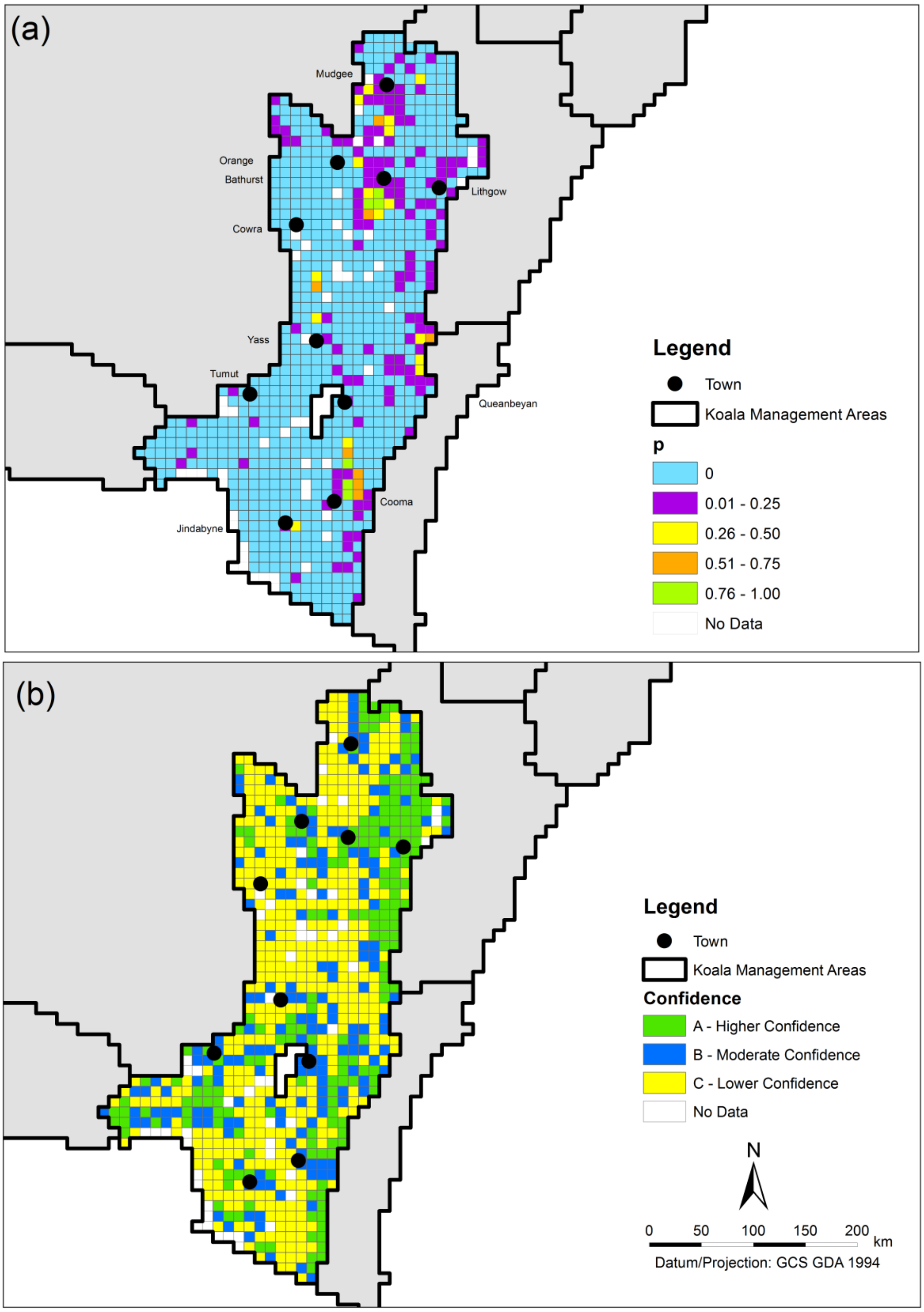


Figure 10: The distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate within KMA 5.

3.7 Koala Management Area 6 – Western Slopes and Plains

While 56% of grid cells within KMA6 record No Data (Figure 11), these are towards the western half of the KMA. The likelihood map (Figure 11a) highlights large and known populations at Gunnedah (Lunney *et al.* 2012, 2009) and the Pilliga forests south-west of Narrabri (Barrott 1999; Kavanagh and Barrott 2001). It also picks up smaller known populations at Moree (Predavec and McMillan 2008) and along the Murrumbidgee River at

Narrandera (DECC 2008). These highlighted populations tend to have moderate or high confidence in the estimates; the rest of the KMA has low confidence (Figure 11b).

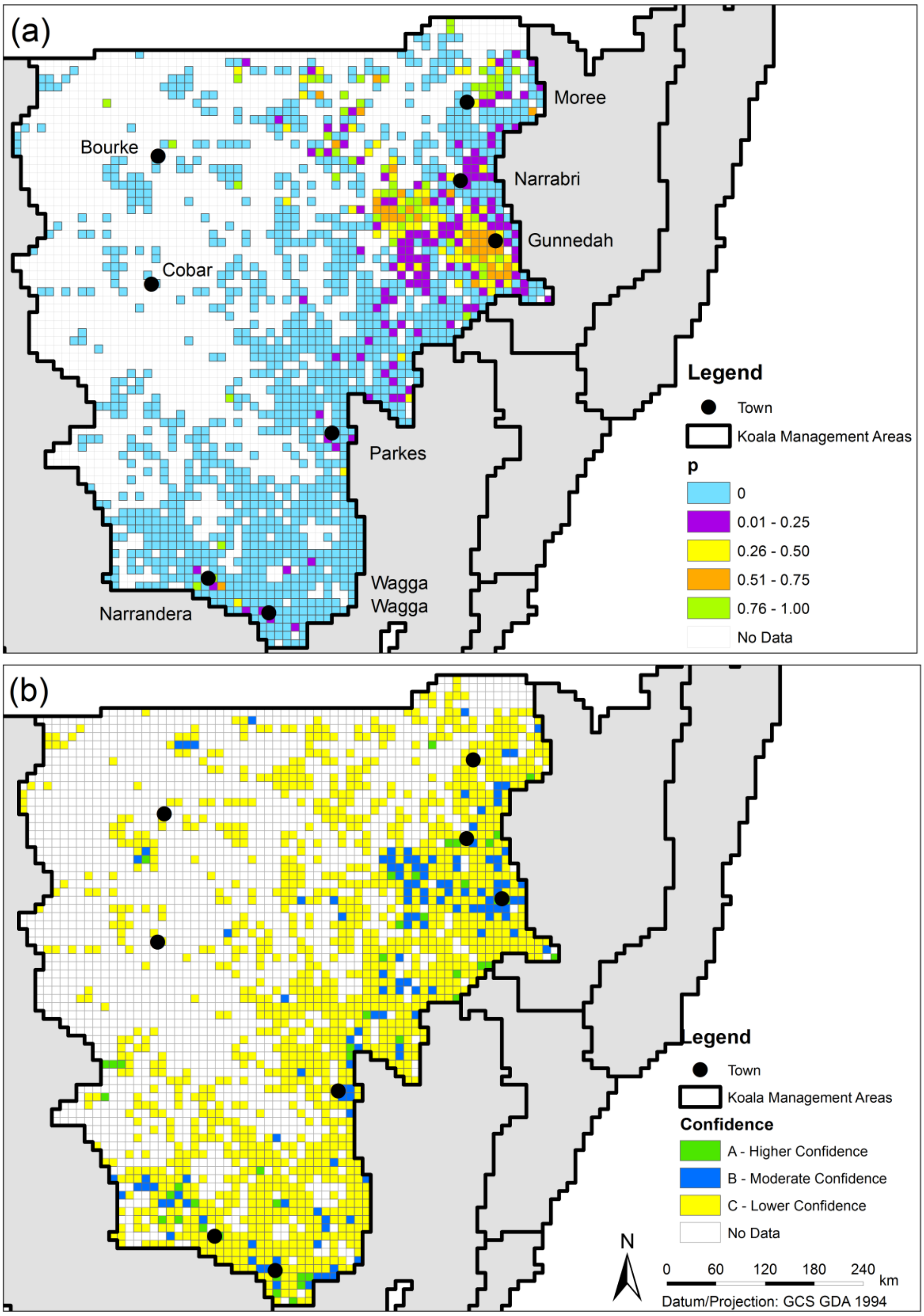


Figure 11: The distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate within KMA 6.

3.8 Koala Management Area 7 – Far West and South West

KMA7 is characterised by the high number of grid cells with No Data (78%) (Figure 12 and Table 5). There are some cells along the Murray River that show low likelihood of koalas (Figure 12a), and this likely corresponds with the distribution of river red gum (*E. camaldulensis*) and coolabah (*E. coolabah*), both primary feed tree species (DECC 2008).

While there are individual koala records in other locations, such as north of Wilcannia *(Ellis et al.* 1997), these grid cells have very low confidence given the very low number of records of any species.

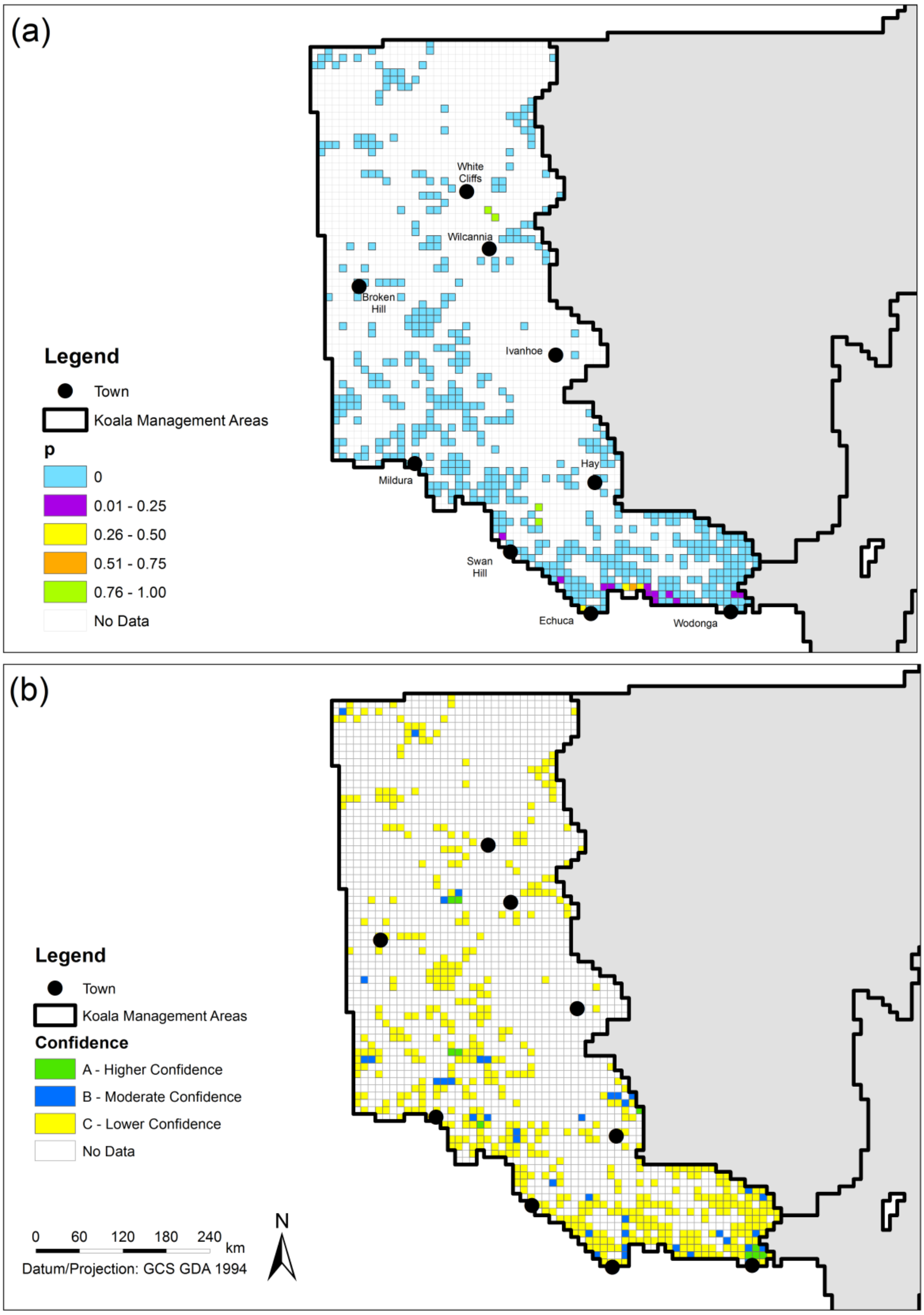


Figure 12: The distribution of (a) the likelihood of koalas (*p*) and (b) the confidence level in the estimate within KMA 7.

4. How to use the map

This chapter outlines how the preliminary likelihood of koala occurrence map may be used within a management framework. The management actions and the values used below are for example purposes only and must be considered carefully for each KMA. The example provided in Figure 13 is constructed and does not represent a real-life situation. There are four steps in determining the likelihood of koalas in a format suitable for management use.

4.1 Step1: Determine the *p* value (likelihood of koalas) for the cell that covers the area of interest.

Each cell in the koala likelihood map has been assigned a value for the likelihood (*p*) based on Equation 1 (see Section 2.1) (Figure 13). These are values between 0 and 1 with a higher value representing a higher likelihood of koalas being recorded. Cells in which no records have been made have a *p* value of '999' (see cell k in Figure 13). A patch of vegetation takes the likelihood value of the cell in which it sits (although see Section 4.5 for possible exceptions).

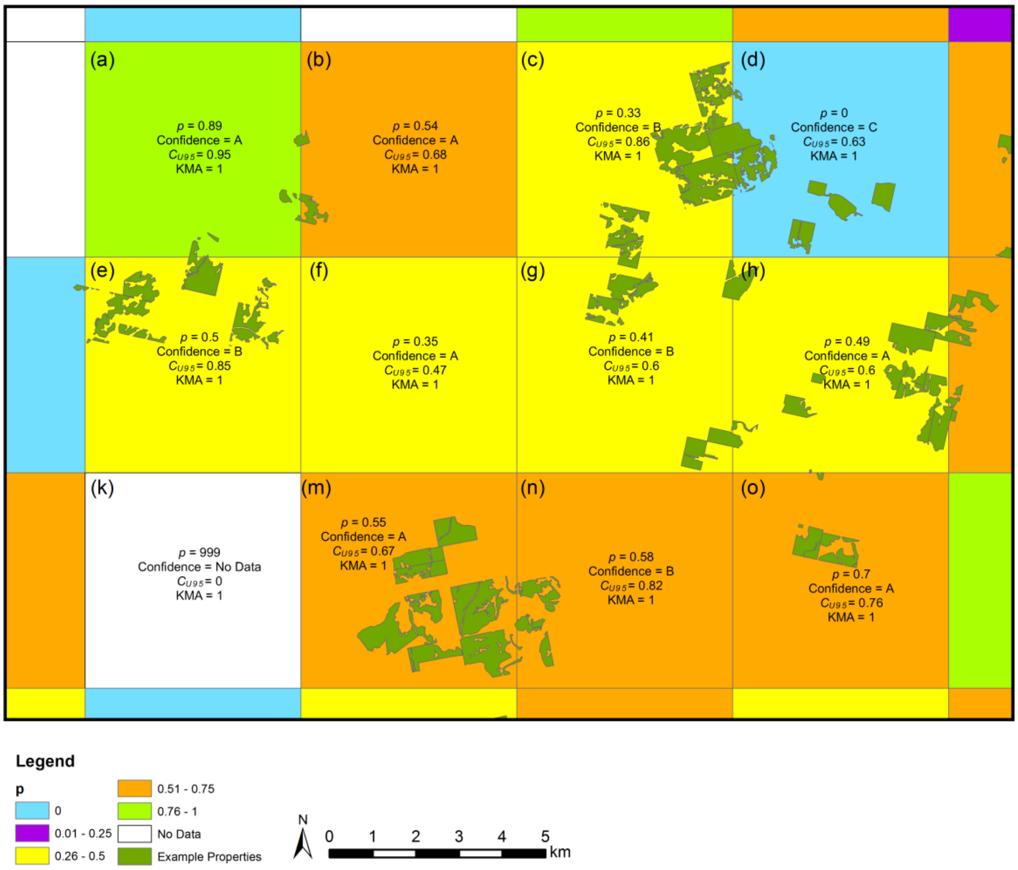


Figure 13: A constructed example of PNF properties and the koala likelihood map.

4.2 Step 2: Determine the confidence for the target cell

Each cell is assigned a confidence level based on the calculations and cut-off values presented in Chapter 2. The confidence levels shown in Figure13 are based on cut-off values for KMA1 (5 kilometre^2) presented in Table 1. Cut-off values can be changed for different management situations.

Using the confidence category for the target cell, apply the rules outlined in Table 6 to obtain the final *p* value.

Table 6: Rules to apply based on the confidence category.

Confidence	What this means	Rule to apply
A	Good confidence in the likelihood estimation	Use the *p* value
B	Moderate confidence in the likelihood estimation	Use the Upper 95% Confidence value (one-sided) instead of *p* OR Collect more data*
C	Low confidence in the likelihood estimation	Collect more data*
No Data	No data are available to estimate likelihood	Collect more data*

* Additional data collection may include field survey or expert opinion.

The map highlights those areas (grid cells) where there is insufficient data to reliably determine an estimate of the likelihood of koalas as well as cells in which there are no data available. Further data could be obtained for those cells through either field survey (with reference to approximate *N* values in Table 2 and considering both koalas and ‘other’ species) or else through expert opinion. Expert opinion could be given along the lines of that outlined in the BioBanking Assessment Methodology (DECC 2008b) and should consider all known sources of information, including the current koala likelihood map, to determine an estimated value of *p*.

As an example, Grid Cell C in Figure 13 has a *p*-value of 0.33 and a Confidence Level of B (moderate confidence). A proponent may either choose the upper 95% one-sided confidence value (in this case 0.86), or obtain further information to improve the confidence in the *p*-value. A change in the p-value from 0.33 to 0.86 would likely change the prescription level for the target cell (see Section 4.3).

4.3 Step 3: Determine the action level for the target cell

An action level may be based on the final *p*-value obtained for the cell and KMA in which the cell occurs. Cells with a higher *p* value (i.e. a higher likelihood of koalas) should be assigned to a higher action (i.e. actions that provide a higher level of protection for koalas) as shown in Table 7. The cut-off values for the action levels are shown only as examples in Table 7 for KMAs 1 and 3. The final values must be determined with careful reference to the overall distribution of *p* values across cells in each KMA, the tenure of cells and the overall level of protection that should be afforded the koala in each KMA.

Table 7: Prescription levels based on p-values and KMA (completed only for KMA1 and 3).

KMA	Action Level A	Action Level B	Action Level C	Action Level D
1	$0.40 \le p \le 1.00$	$0.20 \le p < 0.40$	$p < 0.20$	Conf = C or No data
2	Example only	Example only	Example only	Conf = C or No data
3	$0.10 \le p \le 1.00$	$0.01 \le p < 0.10$	$p < 0.01$	Conf = C or No data
4	Example only	Example only	Example only	Conf = C or No data
5	Example only	Example only	Example only	Conf = C or No data
6	Example only	Example only	Example only	Conf = C or No data
7	Example only	Example only	Example only	Conf = C or No data

4.4 Step 4: Apply the Action Level to the patch of vegetation

The actual action required would depend on the Action Level obtained in Step 3 and the KMA. As an example, the actions in KMA1 (North Coast) may include:

- **Action Level A** may be a prohibition on logging in patches of vegetation that contain koala feed trees and that are over a certain size and/or are connected to patches of a certain size
- **Action Level B** may be retention of 50% of koala feed trees
- **Action Level C** may be retention of 20% of koala feed trees
- **Action Level D** may include further survey or information to be provided.

Actions levels should decrease in level of protection for koalas and should match the protection required for koalas within the KMA. Determining the actions required is beyond the scope of this mapping project and the above are examples only.

4.5 Special case

A special case may apply where a property proposed for PNF covers two cells. In this case:

- if the split of area between the two cells is more even than 20%:80% (e.g. 40:60) then the higher *p*-value from the two cells applies to the entire property and patch of vegetation
- If the split of area between the two cells is less even than 20%:80% (e.g. 15:85) then the *p* value of the cell with the majority of the property applies to the whole property.

As an example, a large patch of vegetation covers grid cells C and D in Figure 13. In this case the *p*-value of 0.33 and the confidence of B would apply to the whole patch of vegetation.

5. Future refinements of the map

The map in this report is a preliminary map of the likelihood of koalas based on a simple proportion of koala records from within a suite of mammal records. It is limited by the availability of data as evidenced by the number of cells across the state with No Data or low confidence values. However it shows clearly where koalas occur with a higher likelihood and these correspond in general with known population centres. The lack of data and low confidence in some cells should be seen as a strength, in that they allow the low confidence situation to be dealt with from a management perspective rather than extrapolating data from surrounding cells.

The map should be considered preliminary and a number of modifications could be investigated in order to refine the map.

- Investigate further filters for the *Atlas of NSW Wildlife* data to account for some of the inherent biases. The focus should be on cells that underestimate the likelihood of koalas, such as where there has been an unusually high level of survey for ‘other’ mammals relative to the koala.

- Determine suitable means for further data collection and expert opinion. Expert opinion could be based on procedures similar to those outlined in the BioBanking Assessment Methodology (refer to Section 4.5 of the methodology) so as to allow consistency across Government.

- Investigate including environmental variables in the baseline mapping. This would allow a better estimate of p based on the methods used in the 2009 Wildlife Research paper (Lunney et al., 2009) or along similar lines to Pennay et al (2011). If consistent vegetation mapping is available for the state as a whole, then this can be used.

- Investigate using a modified version of Generational Persistence (e.g. Biolink Ecological Consultants, 2012). The modified version should include baseline survey effort.

- Determine criteria by which to assess existing koala habitat mapping (e.g. CKPoM mapping) with a view to accrediting suitable mapping. Koala habitat maps have been developed using a range of different methods and based on different data sources. Koala habitat maps should only be used if they provide a better conservation outcome than the baseline map.

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Appendix 1: Distribution models considered

A number of different models were considered in preparing the baseline map, but each had significant limitations or biases and was therefore not used in the final map preparation. These are discussed briefly below.

A1.1 Koala numbers

The simplest way to show the distribution of an animal species is to map where they have been seen. This can be done with points (see Figure 3) or within a grid showing the frequency of sightings within a grid cell (see Figure A1.1).

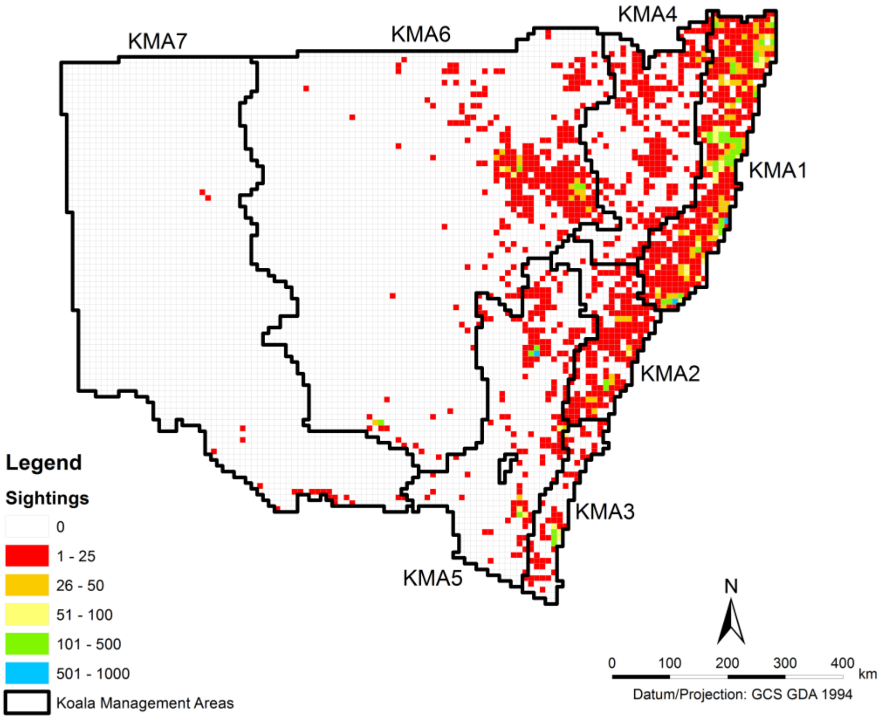

Figure A1.1: The frequency of koala records (1994–2014) within a 10 km^2 grid.

There are two fundamental limitations in such data:

1. The data do not account for variation in survey effort across the grid cells and mapping assumes that detectability of the species is uniform across the map (e.g. Hill 2012). This assumption is rarely met using a wildlife atlas consisting of opportunistic observations. Observations are often focussed on populated urban centres or along roads.
2. The data cannot distinguish between the species of interest truly not being present within a grid cell and a grid cell where the species is present but has not been detected. This limits the spatial extent of useable information within such a map.

A1.2 Generational persistence

Generational persistence aims to identify geographic areas (usually grid cells) where the species of interest has occurred over three consecutive generations. Three generations is the number required to demonstrate a decline under IUCN red book criteria (IUCN 2001). Generational persistence has been used to identify significant koala populations in a number of mapping projects as part of preparation of Comprehensive Koala Plans of Management (e.g. Biolink Ecological Consultants 2013, 2012). While this can identify grid cells in which koalas have been *recorded* in each of three consecutive time periods, it suffers from the same limitations as mapping simple animal observations in that it does not account for variation in survey effort (in this case both temporally and spatially).

A1.3 Estimating distribution – Presence only modelling

A number of modelling methods have been proposed to model the distribution of a species based on presence-only data as is usually found in a wildlife atlas (Elith *et al*. 2006). These models use the occurrence data and a suite of environmental variables to predict the distribution of the species across a geographic range. These methods can be effective and provide a better representation of the geographic distribution of the species. One such model considered in the current mapping project was Maximum Entropy (Maxent) modelling (Phillips *et al.* 2006). This model was not pursued for two main reasons:

1. The model will predict the distribution of the species across the modelled geographic range, extrapolating the findings across areas where there has been little or no survey. The initial simple mapping of koala records indicated a large number of grid cells that contained not only no koala records but also no records of the other mammal species. Extrapolation of modelled results across such cells raises the possibility that management actions would arise from modelled data indicating koalas were scarce in a particular cell when in fact they were abundant (false-negative). A precautionary approach was considered more appropriate within a management framework, identifying cells with low survey effort and dealing with them as part of the overall mapping project.
2. Reliable inference from the model requires several assumptions (Yackulic *et al.* 2013), including:
    a. that observed presences are the consequence of random or representative sampling. This is not the case with data in the *Atlas of NSW Wildlife* (see section A1.1)
    b. that detectability during sampling does not vary with the covariates that determine occurrence probability. This is unlikely with modelled koala data. When observing koalas directly the density of forest can influence detectability (Barker *et al*. 2014) and forest type is a good predictor of koala abundance (DECC 2008). Indirect methods of detection, such as identification of scats under trees (Phillips and Callaghan 2011) can be influenced by a range of environmental factors including forest type and moisture levels (Rhodes *et al.* 2011).

A1.4 Estimating site occupancy – Presence/Absence Models

An improvement on presence-only modelling is to include a measure of absence – presence/absence models (e.g. MacKenzie *et al.* 2009 2003; Rhodes *et al.* 2006). The MacKenzie (2004) method has been used to estimate the distribution of koalas from a state-wide community survey (Lunney *et al.* 2009). This modelling method certainly has potential to determine the distribution of koalas, but in the current mapping project two issues became problematic:

1. Determining the unit of survey. The Crowther *et al*. (2009) paper used respondents from a 2006 community wildlife survey as the unit of survey. Data from the *Atlas of NSW Wildlife* do not immediately lend themselves to determine a standard unit of survey. Two units were considered in the current mapping project:
    a. Records within a sub-grid of 2.5 kilometre^2 (i.e. 16 sub grids within the 10 kilometre^2 grid cell). This greatly simplifies the data, but at the same time increases error with the estimate.
    b. Using the ‘observer’ noted in the *Atlas of NSW Wildlife* records. This has potential, but the data preparation would need to account for differences in how the observer is defined. In some cases the observer is recorded as an

individual, who generally has only a few records associated with them. In other cases the observer is recorded as a corporation with a large number of records associated with them.

c. Accounting for the errors with the estimate when koalas were either absent from a grid or when koalas were the only animals recorded. The model cannot estimate the error in either of these cases. We considered this to be a problem in a management framework. We wanted to distinguish between where koalas are estimated to be absent and we are confident in the results, and where koalas are estimated to be absent but we have low confidence in the result.

The use of presence-absence models warrant further investigation, but the resultant map must be able to account for the problems identified above.

Appendix 2: Map metadata

The metadata record conforms to the current Australia New Zealand Land Information Council (ANZLIC) standard (http://www.nrims.nsw.gov.au/policies/metadata_policy.html).

Dataset	Title	A preliminary map of the likelihood of koala occurrence in NSW
	Custodian	NSW Environment Protection Authority (EPA)
	Jurisdiction	NSW Australia
Description	Abstract	The map presents the distribution of the likelihood of koala occurrence across NSW based on publically available data held in the *Atlas of NSW Wildlife* (www.bionet.nsw.gov.au). The proportion of koalas recorded relative to a suite of other mammals is presented in a 10 kilometre grid across NSW. A 5 kilometre grid is used for Koala Management Area (KMA) 1 – North Coast. A measure of the confidence in the likelihood estimate is also presented. This map can be used as the first step in determining the distribution of koalas across NSW and ultimately contribute towards the assessment of PNF applications.
	Search Word(s)	Koala, likelihood of occurrence, Private Native Forestry
	Geographic Extent Name(s)	State of NSW
Data Currency	Beginning Date	1 January 1994 (first search date from the *Atlas of NSW Wildlife*)
	Ending Date	26 March 2014 (date of search of the *Atlas of NSW Wildlife*)
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	No update planned.
Access	Stored Data Format	ArcGIS Shapefile (ARCGIS 10.1).
	Available Format Type	Digital formats: ArcGIS Shapefile (map layer) and PDF (map report)
	Access Constraint	
Data Quality	Lineage	Location data (koala and other species) were sources from the *Atlas of NSW Wildlife* (accessed 26 March 2014). These data form the basis of the estimates of the likelihood of koalas occurring across NSW and the confidence in the estimates.
	Positional	Records in the *Atlas of NSW Wildlife* include a

	Accuracy	spatial accuracy field. Only records with a spatial accuracy greater than 10 kilometre (the size of the spatial grid used in the state-wide assessment) were used in the preparation of the map.
	Attribute Accuracy	The map includes a measure of the accuracy of the likelihood estimates of the occurrence of koalas based on a 95% confidence interval.
	Logical Consistency	The likelihood of occurrence of koalas within the grid cells should be viewed relative to each other and not as absolute numbers.
	Completeness	The assessment covers all of NSW. The map includes areas that include no records of koalas or of other species. These grid cells are identified in the map layer (*p* = 999, Confidence = No Data). The lack of data in these grid cells is noted and incorporated into the final mapping.
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