Changes in the distribution of the Koala Phascolarctos cinereus after 16 years of local conservation initiatives at Gunnedah, northwest New South Wales, Australia

In the early 1990s the koala became the mascot for a revegetation program to control salinity on agricultural land around Gunnedah in NSW, and in 1990 a snapshot of the koala's distribution in the shire was collected, mainly via a mail survey. At that time, koalas were predominantly reported from areas with more than 40% wooded vegetation remaining in the surrounding 2000 m radius, with the core of their reported distribution being the basalt hills south of the town of Gunnedah. As the local koala population increased, the shire became proactive in koala conservation, adopting the motto "koala capital of the world" in 2002. In a repeat mail survey in 2006 koalas were reported from a wider area within Gunnedah shire, particularly to the north and east of the town and in more developed agricultural areas, but still predominantly in areas with more than 25% wooded vegetation. Koalas were also reported with increased relative frequency in the town, and this formed the core of the reported sightings. There were still no reports from many of the vegetated hilly margins of the shire, and this may be due to under-reporting due to low human visitation or an actual absence due to the nature of the forests on those hills. Since the success of tree plantings in the 1990s, the koala population of the Liverpool Plains has become a focus of increasing local conservation efforts, as well as research to explain koala population dynamics.

(242 words)

Keywords: community survey, citizen science, revegetation, restoration, salinity, Liverpool Plains, koala populations.

Introduction

In NSW the koala has disappeared from large sections of its range, primarily as a result of habitat loss, but this is also due to other threats including early commercial hunting, disease and drought (Reed and Lunney 1990; Reed *et al.* 1990; Gordon *et al.* 2008). Its diminished and fragmented distribution resulted in it being listed in 1992 as a vulnerable species under New South Wales legislation (Lunney *et al*. 2000a). The koala's current distribution in NSW is now concentrated along the coast north of Newcastle, the adjacent slopes, tablelands and immediately west of the Great Dividing Range (Crowther *et al.* 2009; Lunney *et al.* 2009; Predavec *et al.* in press). Koala populations in most bioregions are in ongoing decline (Adams-Hosking *et al.* in press), but the decline has not been even across the state. In Coffs Harbour Local Government Area, on the north coast, the koala population has either been stable or declined only slightly (Lunney *et al.* 2015). Close *et al.* (2015) point to the long-term survival of the low density koala population south-west of Sydney. As McAlpine *et al.* (2015) demonstrate, the national picture is one of major differences across the range of the koala, causing challenges for management and policy.

Around the inland Gunnedah region (Figure 1) the koala population was considered sparse until the 1980s, with Reed and Lunney (1990) noting only one record of a koala before 1949. Numerous reports during a 1986-87 survey (Reed *et al*. 1990) saw the species become a focus of conservation efforts in 1990 and the flagship animal for a major environmental plantings program (Smith 1992) to lower the water table. The overall focus of this program was to combat dryland salinity which was emerging as a major issue and the productivity of some properties was declining (Spies and Woodgate 2004). Part of this program was named "Bearcare", reflecting the value of planted trees for the now expanding koala population, and included an extensive community survey. The aim of the survey was to document the distribution of the koala in the region (Smith 1992) as part of the encouragement by the then NSW Soil Conservation Service to plant trees for koalas and thereby improve soil conditions. Follow up work in 2006 by Rhind *et al*. (2014) found that koalas were using the trees planted in the 1990s, and a 2006 state-wide koala survey (Lunney *et al*. 2009) revealed that the koala population was expanding in the area, in contrast to state trends.

As Gunnedah was one of the few places in NSW with an increasing population of koalas, and because the Gunnedah community adopted the koala as its town mascot, this region and the adjacent Pilliga forests became a focus of koala habitat restoration and research (Barrott 1999, Crowther *et al*. 2009, Crowther *et al.* 2014, Curran 1997, Kavanagh and Barrott 2001, Kavanagh and Stanton 2012, Lunney *et al.* 2012a, b, Paull and Ellis 2000, Rhind *et al*. 2014, Watson 2009). Gunnedah is one of five locations identified in the NSW Koala Recovery Plan (DECC 2008) and in 2006 this area was given extra survey effort in the state-wide community wildlife survey and was again identified as holding a major population of the species (Lunney *et al*. 2009). Consequently we have two detailed snapshots of the reported koala distributions for this region, one at the beginning of the habitat and landscape restoration work in 1990 and one 16 years later, that warranted comparison. Questions asked of the two Gunnedah community koala surveys were:

1. how many koala records were collected?
2. are they occupying the same part of the landscape in each period (the same extent)?
3. do they have the same distribution density (the same core areas)?
4. what habitat features can explain the location of koala reports in the region?

Methods

Study area

The Gunnedah Shire (Figure 1) is west of the Great Dividing Range in north-western New South Wales, Australia and is located primarily in the Brigalow Belt South Bioregion and partly in the Nandewar Bioregion. It includes parts of the fertile Liverpool Plains and covers 4995 km^2 of high quality agricultural land. By 1920, this area had over 70% of its native vegetation cleared or highly modified through the ringbarking trees in an attempt to kill them (Bedward *et al*. 2007). The Brigalow Belt South Indicative Landcover data (Department of Land and Water Conservation, 2002 pers. comm.) describes this modified landscape in the 1990s and shows that 40% of the shire was cropped, 19% was forested, and most of the remaining area was grazing land, with scattered remnant trees. This produced a variegated landscape with a variety of woodland densities. Unlike most agricultural landscapes, where remnants are typically located on poor, unproductive soils (Pressey 1995), the remaining forests around Gunnedah largely occur on fertile basalt soils on hills that are too difficult to crop. This hilly land is mostly managed for timber production and, until 2005, there were no conservation reserves in the shire.

Figure 1 here or may go in introduction

Climatic conditions, particularly weather extremes, are known to influence koala populations (Gordon *et al.* 2008; Seabrook *et al.* 2011; Lunney *et al.* 2012b; Crowther *et al.* 2014; McAlpine *et al.* 2015; Adams-Hosking in press). The climate around Gunnedah is temperate with annual rainfall ranging from 248 to 1138 mm, median value 626 mm. During the 25 years preceding 2006 there were two long periods, each lasting for six years, of above median rainfall. This represented a period of rainfall recovery following an accumulated rainfall deficit of greater than 2000 mm that had amassed since 1878 (Figure 2). Most of that recovery had occurred by 2001 when the Millennium Drought began to impact on eastern Australia, although Gunnedah had above median rainfall in 2004 and 2005. Overall, only six years during the 16 year study period received below median rainfall.

Figure 2 here

Koala records

Koala records were compared between two studies; one conducted in 1990 and the other in 2006. In 1990 there was an intense investigation of koala records around Gunnedah as part of the Bearcare program (Smith 1992). Records were collected via a questionnaire as well as by site inspections. A total of 1021 questionnaires were sent to residents of the Gunnedah Shire. Thirty five questionnaires were sent to individuals who were interested in the project, 616 were sent to schools and 370 were sent to landholders. Additional koala records were gathered by field surveys, from anecdotal accounts, by research and by incidental recordings (Smith 1992).

In 2006, Lunney *et al*. (2009) conducted a state-wide community survey of householders to gauge their knowledge, recollections and opinions about wildlife, including koalas. The Gunnedah Shire was more intensively surveyed than other parts of the State specifically in order to gather information on koalas. A total of 4185 questionnaires were mailed to the postal areas covering Gunnedah Shire requesting information about a range of species, including the koala, with the records of the more common species serving as a guide to where observers were present, even if a koala was not recorded. Participants were asked to specify when they had seen animal species and, for the purposes of this koala study, 'recent' records reflect koala records between 2004 and 2006. The primary details of the survey methods are recorded in Lunney *et al.* (2009), with all the details, including the survey form, are contained in Lunney *et al.* (2010).

Area of occupancy

The area of occupancy is a standard measure of distribution used by the IUCN for species assessments, and is influenced by the scale at which the data are analysed (He and Gaston 2000). At finer scales, the area of occupancy correlates with actual population counts, but this relationship weakens as the scale increases (He and Gaston 2000). For example, Hurlbert and Jetz (2007) demonstrate that, at increasing scales, gaps in distributions due to uneven sampling are reduced. Hartley and Kunin (2003) recommend that distribution data be analysed and interpreted at multiple scales to allow wider and more robust conclusions to be drawn. To achieve this the 1990 and 2006 survey records were converted into separate gridded maps at 1, 5 and 10 km cell resolutions. The cell sizes were chosen to be both greater than the median annual home range size of koalas yet small enough to have multiple cells covering the study area. While koala home ranges and movement patterns can vary considerably across their range (Matthews *et al.* in press), a median annual home range size of 16.6 ha was used based on ranges calculated for 30 koalas in the adjacent Pilliga Forests (Kavanagh and Barrott 2001).

Importantly, the conversion of records to occupied cells helps remove the effect of multiple records for a single area or for a single animal within its home range. Overall, the results are less affected by the density of records, and by multiple records of the same animal, once the sample size is adequate (i.e. more sampling will simply result in more detections in the occupied cells).

Distribution and density

Harmonic mean analysis (Dixon and Chapman 1980) was used to determine the spatial pattern of koala records by calculating the 50% isopleth (representing the densest clusters of records and, by inference, the main location of koalas) and the 95% isopleth (to give the overall distribution while excluding outli ers that could greatly distort the distribution). The distribution and density of records was analysed using the 'Home range analysis and animal movement' extension tools in Arcview™ which implements the harmonic mean analysis for georeferenced datasets (for further information see the US Geological Survey website at http://www.usgs.gov/).

Determining the potential amount of koala habitat in the region

The potential area of koala habitat in the Gunnedah Shire and surrounds was determined by calculating neighbourhood statistics from landcover mapping that was developed as part of bioregional assessments in western NSW (Brigalow Belt South Indicative Landcover 2002, Department of Land and Water Conservation). Statistics were generated for three of the original landcover categories (cropping, timber, and open woodland/grassland) with three other minor categories (urban, water, and wetlands) not used. The distance chosen for creating the neighbourhood statistics was 2000 m around each one hectare grid cell (which equates to 1257 ha around each cell). Hence, for every hectare within the Gunnedah Shire, a cover density value was derived that specified the number of neighbouring hectares that was timbered, cropped etc. This information was then used to determine the relative amount of wooded land cover around each of the koala records.

Results

In 1990, 25 percent (n=254) of the Bearcare questionnaires were answered and returned while a further 23% (n=239) were returned unanswered. Of the questionnaires answered, the following were returned by group: interested individuals 43% (n=15) ; schools 16% (n=98) and landholders 38% (n=141). In total, 809 koala records were collected for the study area, 731 from the questionnaires and 78 from dedicated surveys and other sources. The 2006 mail survey provided a total of 624 koala location records (all records dating back in time),

of which 473 were of animals sighted in the two years preceding the survey, i.e. 2004-2006 (designated 'recent' records). Earlier records were those before 2004 (Lunney *et al.* 2010).

Comparisons between 1990 and recent 2006 koala records showed that the area occupied by koala records was higher for the Bearcare study than for the 2006 study at the finest scale (Table 1). At the coarser scales, the case was reversed, indicating less clumping as well as a wider spread of records (Figure 3). Notable in the 2006 survey was the presence of recent records north of the Namoi River. Smith (1992) reported that koalas were considered rare in that area, as shown in the 1992 maps in Figure 3. Comparatively, the 2006 results show more records along roads, but not in between, and more along roads to the north (across the Namoi River) and east (adjacent to the river) but both surveys show strong reporting around Gunnedah town.

Table 1, Figure 3 here

The distribution of koala records altered between the two surveys (Table 2, Figure 4). The centre of reporting shifted from the hills with remnant forest that are located 7 to 20 km south of Gunnedah township to the town itself. This also resulted in a smaller core area. The 95% isopleth for the 2006 survey data shows the spread of the koala's distribution to the north-east compared to the earlier survey, and it also encompassed a larger area, indicating a more diffuse reporting of koalas.

Table 2, Figure 4 here

The relationship between both the 1990 Bearcare and the 2006 koala record sets and the vegetation cover was examined to determine if koala locations could be explained by the availability of suitable habitat and if that relationship had changed over time. As koala records represent presence-only data, this relationship is not easy to examine statistically. The attribute chosen to illustrate vegetation cover was woodland and timbered vegetation areas within a 2000 m radius of each hectare. This value ranged from 0 to 1257 ha (0 = completely cleared areas; 1257 = continuous wooded remnants) and these ranges were indeed found. The results are presented as density kernels calculated in the R statistical package (R Core Development Team 2013) in Figure 5 and they are mapped spatially in Figure 6.

Figure 5 , Figure 6 here

The frequency kernel of wooded land (line 1, Figure 5) shows how common various levels of clearing are within the Gunnedah Shire. It includes the impact of the forested

hillsides on the results, where extensive sections of contiguous woodland and forest exist on hilly areas, causing the sharp peak at the extreme right of the graph. The small broad peak on the left of the graph (across the range of 0 to 10 ha of the wooded land remaining) shows that cleared areas are relatively common in the Shire, but not widely contiguous. Overall, the results show a wide variety of wooded land densities. The Bearcare koala records (line 2) did not occur randomly throughout the Shire (i.e. had a different kernel from that for the frequency amounts of wooded land) and they were rare in cleared areas and increased markedly once the surrounding density of wooded land rose above ~ 40% (i.e. at least 500 ha of wooded land within 2000 m of a record). In contrast, in the 2006 survey (line 3), koalas were relatively more frequently reported in areas with as little as 25% wooded land in the surrounding area. This indicated an increased reporting rate in agricultural lands, however the reporting rate dropped in areas of more extensive wooded vegetation. As shown in Figure 6, koala records clearly occur in greatest number in, and adjacent to, wooded areas and are least common in the centre of extensively cleared areas. The new records (2006 survey) of koalas north and east of the Namoi River fall within wooded areas, but there are large areas of wooded land at the boundaries of the Shire that lack koala records from either survey.

Discussion

The lack of a structured sampling regime in many community surveys (now promoted under the citizen science banner; see Predavec *et al.* in press), means that it is most unlikely that an animal will be reported as present if no people are living in, or frequently moving through, a particular location. Consequently a lack of records may not represent a true absence. One way of overcoming this problem is to expand surveys to include other species, and thus records of other species serve as a marker indicating where people are looking, but not seeing the target species. This was the principle underlying the 2006 koala and other wildlife surveys reported in Lunney *et al.* (2009; 2010). This method allowed us to calculate the likelihood of a koala being present, even if not reported. This technique to deal with absence data had not evolved by 1990, so the 1990 Bearcare survey had to assume that no records meant no koalas. Field surveys results and incidental records at the time supported that interpretation. However, the presence of koalas in the wooded locations was not seen as important in the 1990 survey because the focus was on cleared agricultural lands where salinity levels were rising and threatening the productive lands.

This study shows that reporting of koalas around Gunnedah shifted between 1990 and 2006, and became centred on the town, rather than in areas in the adjacent hills. There are two possible explanations for this change, and both might be correct to various extents. From their 2006 mail survey, Lunney *et al*. (2009) determined that respondents mostly reported animals near to their place of residence. It follows, therefore, that one set of explanations for the observed change in reporting is that there are relatively more koalas in town, or that the respondents to the 2006 survey were more town orientated, or perhaps they were more willing to report koalas since the shire adopted the motto "Koala capital of the world" in 2002. Alternatively, the results regarding the core range of koalas are relative, and the

proportionally lower number of koala records from areas with extensive woody vegetation (points with > 800 ha of the surrounding landscape wooded) and the basalt hills south of the town may be due to the 2006 survey not having a field survey component, unlike the Bearcare study. Certainly, it could be expected that there are low public reporting rates for koalas that reside in continuous woodland and forest on the hilly parts of the shire due to low visitation by people and low visibility.

The continuous wooded land on the hills in the Gunnedah shire could be suitable for populations of koalas since koalas were estimated to be present in large numbers within extensive areas of continuous woodland in the neighbouring Pilliga forests (e.g. Kavanagh and Barrott 2001, Paull and Ellis 2000). The true situation could be determined by some dedicated surveys of the extensive woodlands at the margins of Gunnedah shire, particularly at the northern-most and eastern-most parts of the shire, which are furthest from the recorded locations of koalas.

If the koala population has genuinely become urbanised, then the town residents must be showing consideration for, or more awareness of, their cohabitants. Urban areas are well known for their threats to koalas, particularly from dogs and motor vehicles (Lunney *et al.* 2007; DECC 2008; McAlpine *et al.* 2015). Townships, however, may also provide some benefits for koalas, particularly during hard times. Koalas are seriously threatened by climatic extremes and especially need shelter from heatwaves (Crowther *et al*. 2014). After this study, in 2009, drought and heatwaves combined to kill an estimated 25% of the koalas around Gunnedah and chlamydia (a disease affecting fertility) became prevalent when it was previously absent or rare (Lunney *et al.* 2012b). Within the town, the koalas in the parks and private gardens, had access to artificial watering, such as dog bowls and garden ponds, which would have provided a degree of refuge from these climatic threats and hence allowed for an increase in density in the town, even when faced with the threats of dogs and motor vehicles. Outside of town koalas exposed to the heatwave conditions were reliant on the vagaries of natural rainfall to obtain water.

While the core area comparisons results between 1990 and 2006 koala records are influenced by relative density of records due to uneven sampling effort, the area of occupancy results at certain grid sizes are less affected by the density of reporting and may be closer to the actual changes that occurred. In particular, the area of occupancy mapping shows that the newer records are widely dispersed and spreading to new areas. Some of the expansion may be due to an increased willingness by landholders to report koalas on their properties. However, we know some of this expansion was because koalas have been using trees recently planted in the cleared agricultural landscape as part of the Bearcare program (Rhind *et al.* 2014) and in revegetation efforts along the Namoi River (Watson 2009). These rapid colonisations, due to the koala being one of the few native arboreal mammals that does not depend on tree hollows for shelter, should provide encouragement for continued restoration of koala habitat. We note that this expansion is adjacent to the 1990 koala populations and is close to wooded areas, not into the centre of extensively cleared areas. With the possible loss of some *Eucalyptus* species from the region with climate change, this rapid response to planting also gives the opportunity to use either replanting stock of the same species but sourced from a

different climatic provenance, or to use alternative species to ensure the survival of food trees for koalas around Gunnedah.

The protective attitude of the residents towards koalas, combined with the revegetation work, should allow the range of koalas in the shire to expand and establish a sustainable population. Continued revegetation work can add to the available koala habitat and can be established in those areas safest from human and climatic induced mortalities. Research is continuing into the koala population on the Liverpool Plains in and around Gunnedah with an increasing emphasis on leaf chemistry, soil chemistry, diseases, tree choice and movement patterns as a part of a larger endeavour to understand and conserve the koala population of the area. The Local Land Services is also promoting koalas and koala habitat measures and the Gunnedah shire council has a koala management strategy. In short, there is now considerable interest in the local koala population, but some issues remain unresolved. Among them are the long-term changes in the koala population since European settlement, and it is our view that a sustained effort to record changes in the koala population is warranted, along with seeking to understand the causes of the changes.

(3690 words)

Acknowledgements

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Tables

Data set	Occupancy 1km grid	Occupancy 5km grid	Occupancy 10km grid
Bearcare 1992	392	85	31
2006 all records	352	110	46
2006 recent records	283	99	42

Table 1. Area of occupancy (number of cells) by koala records from the two surveys.

Data set	HM 50%	HM 95%
Bearcare 1992	18 2	14 64
2006 recent records	14 0	22 34

Table 2. The area covered by the core (50%) and 95% harmonic mean (HM) analysis results in square kilometres.

Figures

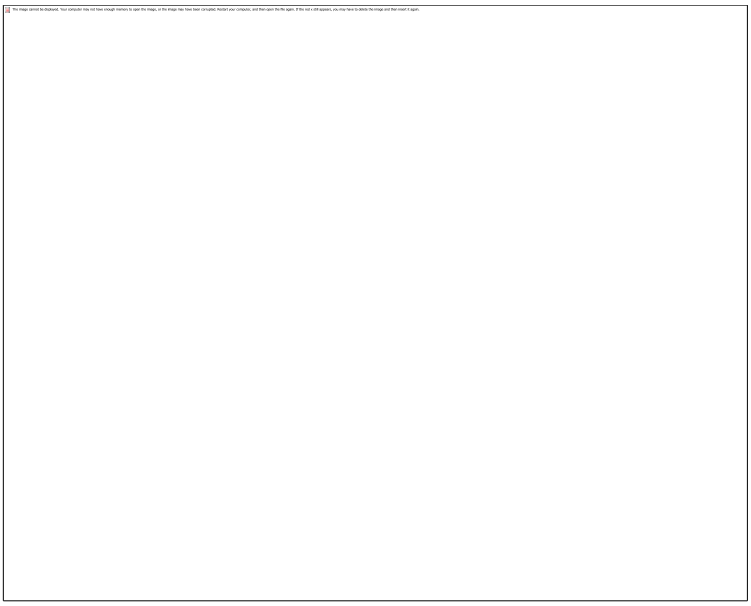

Figure 1. NSW koala records from 1980 to 1990 held by the Office of Environment and Heritage (Ellis and Etheridge 1993). The location of Gunnedah Shire (shaded), the Pilliga forests and the city of Newcastle are highlighted.

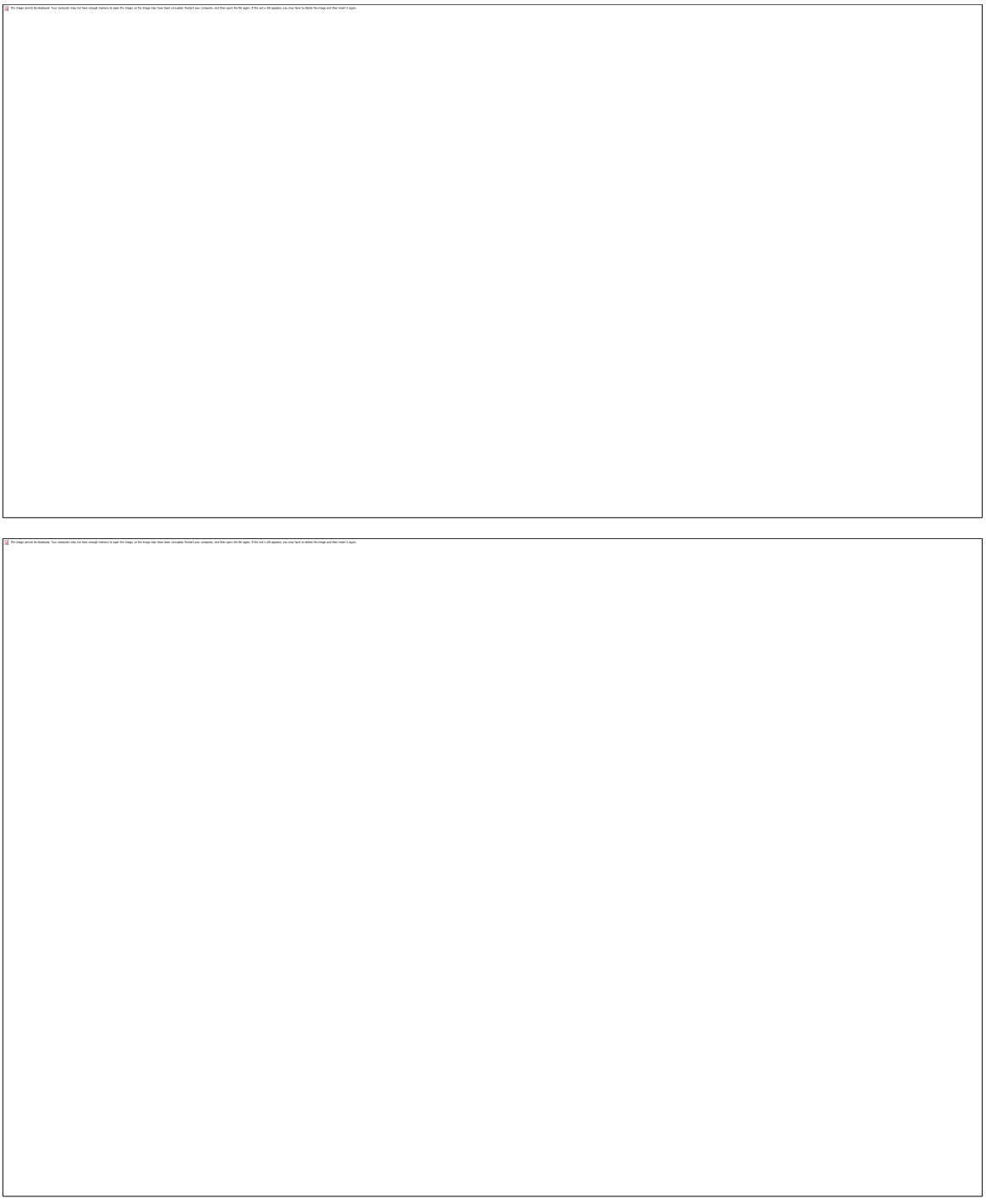

Figure 2. Rainfall deficit compared to the accumulated mean (top) and annual rainfall totals at Gunnedah (bottom) from 1980 to 2010. Light columns are below median rainfall while dark columns are above the median rainfall.

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Figure 3. Bearcare survey koala records (left) and 2006 koala survey (recent records) (right) at a 1, 5 and 10 km grid cell resolutions from top to bottom

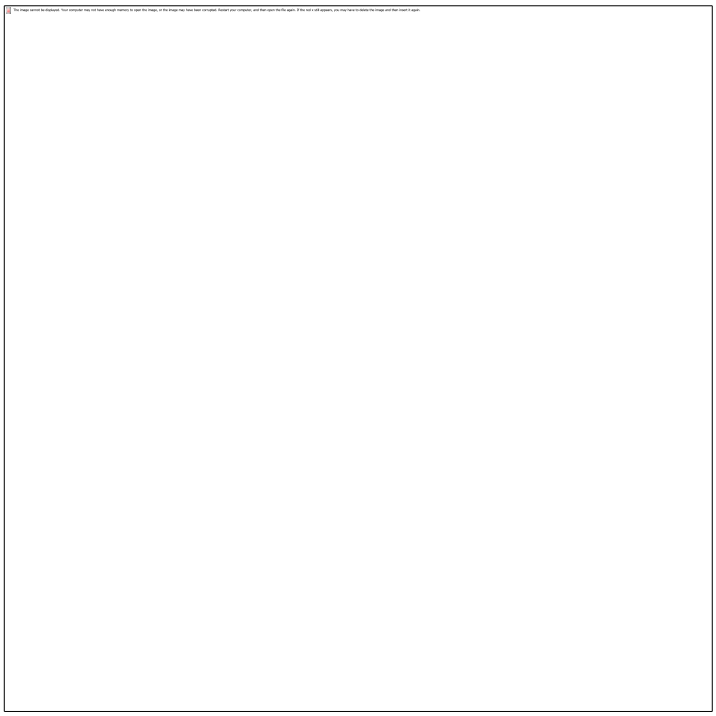

Figure 4. The harmonic mean analysis of the 1990 Bearcare koala record distribution showing the core (50%) range (dark grey shading) within the 95% range (grey shading). The respective results for the 2006 koala record distribution are represented by thick and thin lines. The Gunnedah Shire boundary is outlined in heavy black.

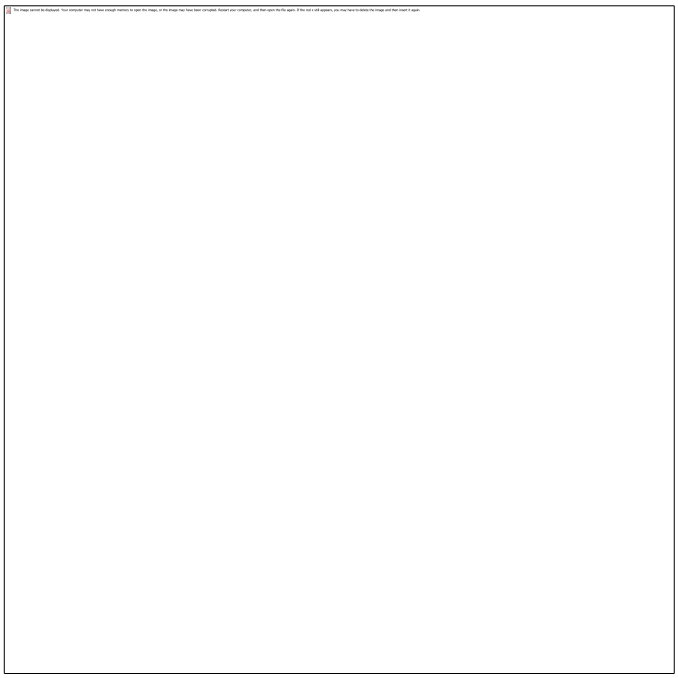

Figure 5. Density kernels of the amount of wooded land surrounding: 1) any given hectare in the shire which ranges from zero (all area cleared or naturally untimbered) to a maximum of 1257 ha (all land within 2000m is timbered), 2) the Bearcare koala records, and 3) the 2006 survey koala records.

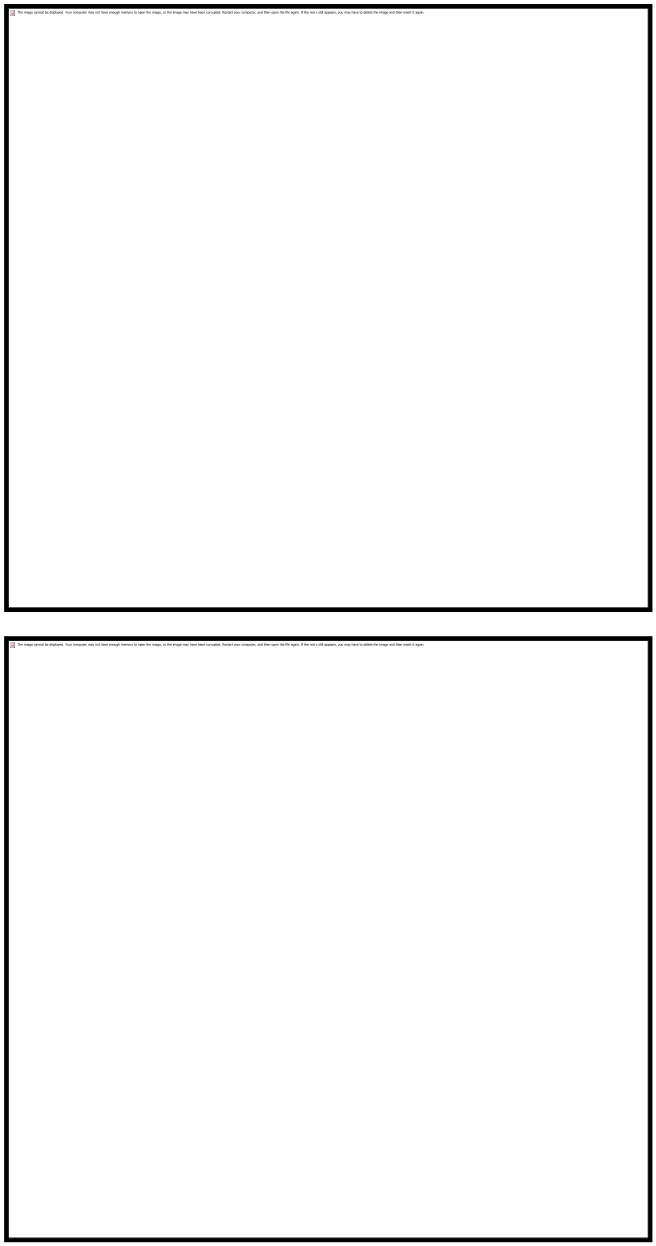

Figure 6. Map of wooded lands density in the Gunnedah Shire and surrounds, ranging from 0% (white) to 100% (dark grey) cover within 2 km, overlain with the 1990 (Smith 1992) (top) or the 2006 (bottom) koala records.