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Interpreting patterns of population change in koalas from long-term datasets in Coffs Harbour on the north coast of New South Wales

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Abstract. We examined a long-term, repeat dataset for the koala population within Coffs Harbour Local Government Area. Analyses of these data have led to the conclusion that, following a perceived population decline in the 1980s, the koala population of Coffs Harbour has endured between 1990 and 2011 and showed no evidence of a precipitous decline during this period. Rather, the population change is best characterised as stable to slowly declining. This conclusion appears to contradict a common view of recent koala population declines on the north coast of New South Wales. There are four possible explanations for the population's apparent stability: that conservation efforts and planning regulations have been effective; that surviving adults are persisting in existing home ranges in remnant habitat; that the broader Coffs Harbour population is operating as a 'source and sink' metapopulation; and/or that the standard survey methods employed are not sufficiently sensitive to detect small population changes. These findings do not mean there is no need for future conservation efforts aimed at koalas in Coffs Harbour; however, such efforts will need to better understand and account for a koala population that can be considered to be stable to slowly declining.

Additional keywords: citizen science, conservation, environmental planning, long-term monitoring, *Phascolarctos cinereus*, threatened species, urban wildlife.

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Introduction

In 2012, the combined koala (*Phascolarctos cinereus*) populations of Queensland, New South Wales (NSW) and the Australian Capital Territory (ACT) were listed as Vulnerable under national environmental law (*Environment Protection and Biodiversity Conservation Act 1999*) (Threatened Species Scientific Committee 2012). This listing, based on the best scientific evidence of the day, came after a lobbying campaign from conservation groups, two unsuccessful nominations and an Australian Government Senate enquiry (Senate 2011; Shumway *et al*. 2015). The earlier nominations were unsuccessful because of the difficulty of reconciling the decline of koala populations in the north of the range (Queensland, NSW and ACT) and the issue of abundant, if not overabundant, populations in Victoria and South Australia. The Commonwealth Scientific Committee also felt that there were insufficient data available to determine whether koala populations had declined by more than 30% over three generations (20 years in the case of the koala), as required under the Act. Even the advice provided to the Federal environment minister by the Scientific Committee relating to the 2012 koala listing states that 'data available for [the] assessment remain extremely patchy, inconsistent and incomplete' (Threatened Species Scientific Committee 2012). However, the committee did find evidence of significant koala population declines within the north of its range, and it overcame the north–south dichotomy by listing only the combined populations of Queensland, NSW and ACT.

Within NSW, the legislative realisation of a decline in koala populations came much earlier than at the Federal level. A State-wide community survey (now called citizen science) of koalas in 1986–87 (Reed *et al*. 1990) came to the conclusion that koalas had been lost across 50–75% of their range in the State. As a result of this finding, the koala was listed as 'vulnerable and rare' under the *National Parks and Wildlife Act 1974* as amended by the *Endangered Fauna (Interim Protection) Act 1991* and it is now listed as Vulnerable under the *Threatened Species Conservation Act 1995*. A recovery plan for the koala has been in place in NSW since 2008. Within NSW there have been no studies to estimate the size of the NSW koala population: decisions about its status and decline have been based largely on the changes in its distribution, and population estimates that do exist for NSW are best described as 'reasonable guesses although each can be justified' (Department of Environment and Climate Change 2008).

The difficulties of the listing of the koala at both Federal and State levels do not mean that examples of population declines do not exist, yet there are not many because of the lengthy timeframe required to determine a true population decline. Most studies of koala populations are simply too recent to warrant follow-up looking for changes, but when a second generation of studies is implemented after more than a decade, the results have generally revealed a population decline. In south-western Queensland, the koala population declined, with climate change and loss of habitat from land clearing identified as the causes of the change (Seabrook *et al*. 2002; Seabrook *et al*. 2011). Similarly, in south-eastern Queensland the koala population has shown a decline from multiple threats associated with urban expansion (Dique *et al*. 2000, 2003; Rhodes *et al*. 2011*b*). In Eden, in south-eastern NSW, the koala population was found to have dwindled over the last 120 years to now be on the edge of extinction, with the recent impact of climate change compounding the impacts of loss of habitat and the rise in the human population (Lunney *et al*. 2014). In some of these projects, community surveys and searches for koala dung under trees were the methods employed. Thus, shifts in distribution were the primary means of assessing changes in populations of koalas. Similarly, in the NSW State-wide koala surveys in 1986–87 and 2006, the citizen science approach using community knowledge revealed changes, mostly contractions, in distribution (Reed *et al*. 1990; Lunney *et al*. 2009; Santika *et al*. 2014). In Iluka, at the mouth of the Clarence River, in the Clarence Valley Local Government Area (LGA) to the immediate north of Coffs Harbour, a more intense koala study was possible because the Iluka peninsula is far smaller than the entire LGA. Using radio-tracking and direct counts from walked transects, as well as repeated community surveys, the koala population was found to have been lost from the peninsula (Lunney *et al*. 2002*b*), although more recent studies have shown a recovery in the population (Biolink Ecological Consultants 2012). Collectively, these studies have put all on notice that local koala populations can contract over a long timeframe and even slip to local extinction within a decade or two.

Recent studies are now demonstrating, however, that not all populations of koalas are declining. Close *et al*. (2015) have put forward the view that the low-density koala population of Campbelltown is in fact increasing and that such populations may be more common in NSW than we currently think. They use evidence of a hard-to-detect, low-density population near the Tarlo River (NSW) as an example that such populations can persist. The background studies for the Lismore Comprehensive Koala Plan of Management (CKPoM) indicated that, although the local koala population was significantly reduced in the past, it now appears to have been recovering over the last three koala generations (Biolink Ecological Consultants 2011). This finding was due to the significantly greater area of the LGA occupied by koalas since 1993, compared with the three koala generations before 1993. Similarly, a State-wide community survey in 2006 demonstrated that the koala population of Gunnedah in the central-west of NSW was increasing, in stark contrast to unchanged or declining populations shown in the rest of the State (Lunney *et al*. 2009). These studies, and those indicating a decline in koala populations, identify that we cannot treat the koalas of NSW as a single homogeneous population and that different local koala populations may show markedly different population trajectories.

In this study, we examined a long-term, repeat dataset for the koala population within Coffs Harbour LGA on the north coast of NSW. The koalas of Coffs Harbour became a focus for research following the 1986–87 State-wide survey (Reed *et al*. 1990) and a koala summit in 1988 (Lunney *et al*. 1990), which identified that this area represented a stronghold for the species, although declines had occurred. A more focussed community survey of koalas was carried out in the Coffs Harbour LGA in 1990 which, combined with a field survey in 1996, led to the preparation of the first CKPoM for an LGA prepared under State Environmental Planning Policy 44 – Koala Habitat Protection (Lunney *et al*. 1999*a*, 1999*b*, 2000*a*, 2000*b*, 2002*a*). Here we present data from repeat community surveys in 2006 and 2011, a repeat field survey in 2011, and koala records of a wildlife carer group. The aim is to understand koala populations in a changing rural–urban matrix as an essential prerequisite to effective koala conservation, and not assume that because the local koala population is still present that it will continue to endure.

Methods

The study area

Coffs Harbour LGA, on the north coast of NSW (Fig. 1), currently covers an area of 117 371 ha, including 21 354 ha in the north added in 2005. The study area for this project is the pre-2005 LGA boundary covering an area of 96 017 ha (Fig. 1), allowing comparison of data from 1990 with the data from 2006 and 2011.

The study area and LGA are located between the Bellinger Valley to the south, the escarpment of the Great Dividing Range and the sandstone ridge of the Corindi Plateau/Coast Range, which separates the area from the Clarence Valley in the north. The western half of the study area consists of undulating and hilly land with an elevation to 700 m cut deeply by gullies. The coastal plain is ~10 km wide in the south and includes the Repton, Bonville and Sawtell areas; it narrows in the centre of the study area where the coastal range comes within a few kilometres of the sea.

Although no major river runs through the study area, several smaller rivers and creeks run from west to east (Fig. 1).The geology of the area is mainly sedimentary rock with quaternary sandstone and alluvium along the coast and in the river valleys. In the north, the Woolgoolga/Corindi area along the coastline is less fertile, with soils derived from a geology that is different from that in the south (Lunney *et al*. 1999*a*).

Coffs Harbour has a subtropical to warm temperate climate. Temperatures, on average, reach a daily maximum of 27°C in summer and 19°C in winter (Bureau of Meteorology 2014). Coffs Harbour experiences moderate to high rainfall of ~1850 mm per year. Rain is more prevalent in the late summer to early autumn period (Bureau of Meteorology 2014).

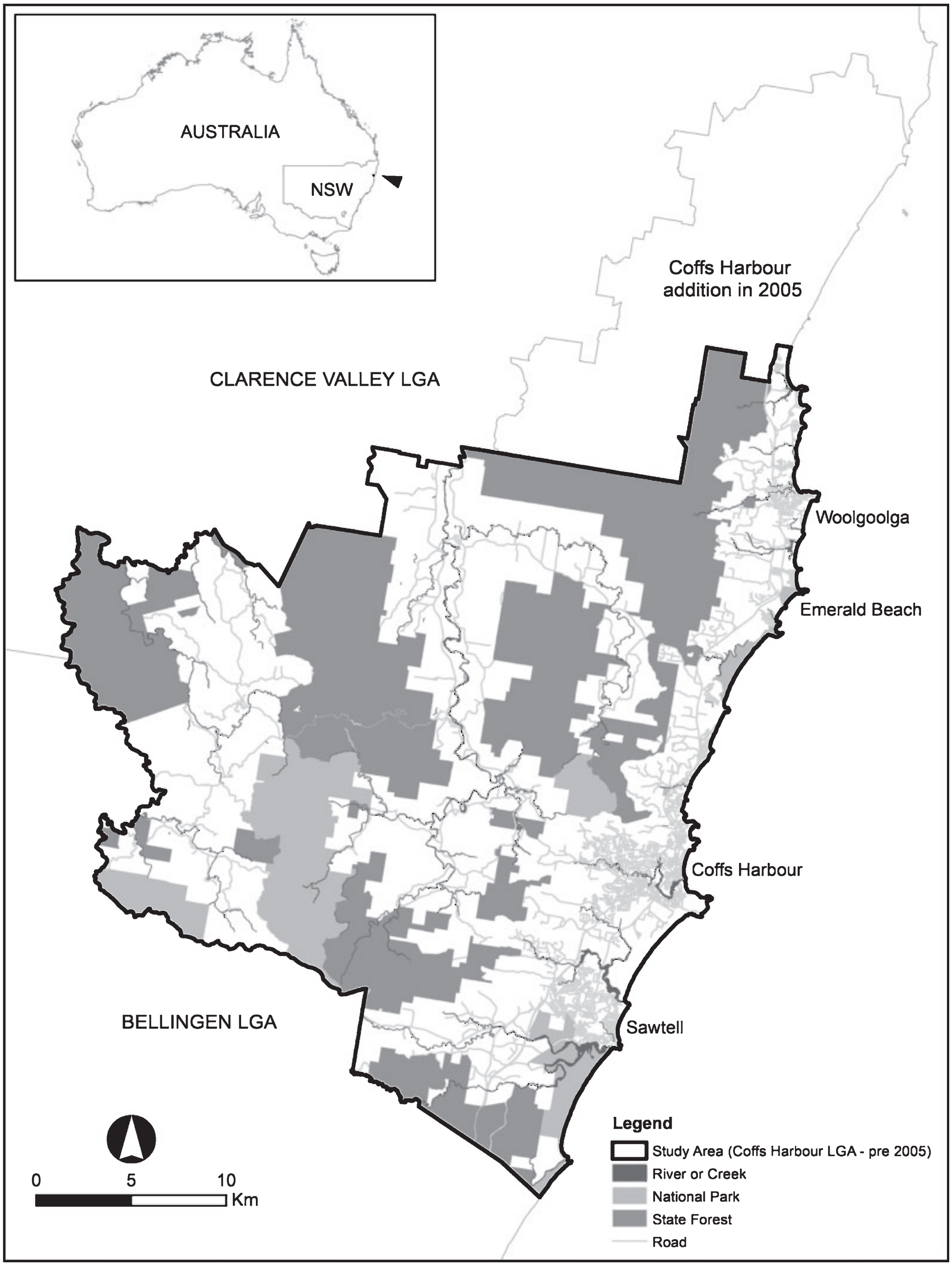

Fig. 1. Study area, showing the higher density of human occupation (as shown by the road network) in the south-east of the local government area in and around areas such as Coffs Harbour and Sawtell.

Variations in local climates throughout the LGA have resulted in wide variations in vegetation communities (Fisher *et al*. 1996; Office of Environment and Heritage 2012). Most of the fertile creek catchments, as well as much of the coastal plain, have been cleared for agriculture or settlement, but ~68% of the study area remains tree covered. Moist open-forest communities dominate vegetated parts of the Coffs Harbour LGA, with a coastal sclerophyll complex along the coast, dry open forest to the north, and rainforest in the south-west (Office of Environment and Heritage 2012). Approximately 34 220 ha (36%) of the study area are State Forest and 8100 ha (8%) are National Park (Fig. 1).

The current human population is ~70 000 having increased from ~18 000 in 1960 and at the rate of ~1% every year for the last 10 years (Australian Bureau of Statistics 2014). The Coffs Harbour Settlement Strategy (Coffs Harbour City Council 2008) predicts that a further 32 000 people will reside in Coffs Harbour LGA by 2031.

Community surveys

A map-based community survey, initiated in October 1990 and completed in early 1991, was an integral part of data collection leading to the preparation of the Coffs Harbour CKPoM (Lunney *et al*. 1999*b*). It was a postal survey asking questions on koala sightings, as well as the community's perception of changes in koala numbers (increasing, decreasing, staying the same), health and threats. Since an objective of the study was to assist land-use planning and day-to-day management considerations, a desired outcome was to produce a map-based picture of the local koala distribution, and respondents were asked to mark sighting locations on a map along with the year that the koala was seen. The 1990 survey generated 2018 responses and 3159 koala sightings within the study area. The survey asked questions only about koalas, not other species, but it did ask questions about respondents' attitudes and support for various management actions (Lunney *et al*. 2000*b*, 2002*a*).

Although the community surveys were focussed on private lands, most fertile land is in private ownership (Pressey *et al*. 1996) and it is these lands that are favoured by koalas (Lunney *et al*. 2009). This allows us to conclude that community surveys adequately capture the distribution of koalas in the study area (Threatened Species Scientific Committee 2012), especially on private lands – a notoriously difficult tenure to survey for wildlife.

There is a rapidly growing use and appreciation of the value of citizen science (Bonney *et al*. 2009; Silvertown 2009) and it has direct applicability to koalas because they are iconic and memorable (Sequeira *et al*. 2014; Predavec *et al*. in press). However, it is also apparent that for this method to be effective we need an equal effort in the science component of this technique. We asked respondents in the 1990 community survey how long they had lived in the study area and to note the years in which they saw koalas. Although the oldest year in which a koala was recalled to have been sighted was 1921, respondents recalled sighting only very few koalas earlier than 1981. We plotted the number of koalas recalled by respondents in each year, divided by the number of respondents who were present in Coffs Harbour in that year, against the year for the decade 1981 to 1990. This gives the number of koalas recorded per respondent as an index of the koala population size. Data that include people's memories over time usually fit a negative exponential curve known as a forgetting curve (Ebbinghaus 1885; Averell and Heathcote 2011): that is, people remember recent events better than they do older events. Although memory retention is usually measured over short periods (e.g. minute, hour and days: Averell and Heathcote 2011), a long-term study over 15 years showed that people's memory of events over time are monotonic and non-linear and that they show a gradual decline over time (Squire 1989). To estimate the forgetting curve, we assumed that the difference in koalas seen per respondent comparing 1989 and 1990 was due to people forgetting they had seen a koala in the earlier year and not due to a change in the koala population. This gave a maximum forgetfulness value of 35% (i.e. there were 35% fewer koalas recalled in 1989 compared with 1990). We then calculated an average forgetfulness value across five years (1990 to 1986 in one-year increments) of 24%. Using the maximum and average forgetfulness values separately, we adjusted the sightings of koalas per respondent in each of the 10 years of 1980 to 1990 by increasing each by the forgetfulness value. We then fitted an exponential curve to the adjusted data, giving the estimated number of koalas seen per respondent taking into consideration a value of forgetfulness (35%-adjusted-values $y = 0.2669e^{0.1786x}$, 24%-adjusted-values $y = 0.3125e^{0.021x}$). We used exponential curves since they better fitted the pattern seen in the data than linear equations. Based on the two adjusted fitted curves, we calculated the change in koalas seen per respondent between 1981 and 1990.

A similar postal, community koala survey was completed in 2006, across the whole of NSW, with one particular focus being Coffs Harbour LGA (Lunney *et al*. 2009). The additional focus included a higher degree of media promotion of the survey relative to the rest of the State and more survey forms distributed. This survey returned 298 sightings of koalas within the study area from 211 respondents. A third, State-wide community koala survey was undertaken between 2009 and 2011, using a web-based interface. This survey returned 133 sightings of koalas within the study area from 54 respondents. Given the smaller number of respondents in the 2006 and 2009–11 surveys compared with the 1990 survey, we combined the results of the two latter surveys. The timing of the two latter surveys, and the phrasing of the questions asking about recent sightings of koalas, meant that there was little chance of duplication of sightings. Further, respondents to the 2006 survey who had provided contact details were contacted regarding the 2009 survey asking them to provide sightings made since the 2006 survey. The 2006 and 2009–11 surveys asked respondents about a range of other species in addition to koalas. These species were used to indicate locations where people had been observing wildlife but where koalas have not been observed. The addition of these species allows presence–absence modelling to be completed (Santika *et al*. 2014). However, given that the 1990 data included only presence of koalas, the absence data were not included in the current comparisons. Similar to the 1990 survey, these later surveys asked respondents about their perception of koala population change.

In order to describe the distribution of koalas at the two periods (1990, 2006–11), and the changes between them, the study area was divided into a 1-km grid, giving 854 complete cells (i.e. incomplete cells that straddled the border of the LGA were not included). We chose the cell size of 1 km since earlier analysis of the 2006 community survey (Lunney *et al*. 2009) indicated that spatial accuracy in the survey was ~1 km and therefore a larger cell size would have greatly expanded the area of influence of each record. It is recognised that in such community surveys the same animal may be sighted several times, but cells would need to be greater than 10 km before independence is reached (Lunney *et al*. 2009). Within Coffs Harbour, both the human and the koala populations are not evenly distributed, with a higher density of both in the south-east of the LGA. We tested how well the community survey sampled the distribution of koalas across the study area by taking cumulative random samples from the 1990 data, for sample sizes between 1 and 3159 (the total sample size in the 1990 survey). Each koala sighting was sampled only once in each cumulative sample run (i.e. without replacement). For each sample, the area of occupancy based on the 1-km^2 grid cells was calculated (i.e. the number of unique cells containing at least one koala sighting). We repeated this sampling 50 times and calculated the average area of occupancy for each sample size between 1 and 3159. We plotted the average area of occupancy against sample size. We assumed that if the sampling curve levelled off, the community survey represented the true distribution of koalas within the study area and that further survey effort would not have increased the distribution. Additionally, the degree to which the curve deviates from a 1 : 1 curve gives an indication of how spatially clumped the survey responses, and possibly the koalas, were.

We compared the survey responses from 1990 with those from 2006–11 in three separate ways: the distribution of koala sightings; the number of koala sightings per respondent as a measure of population size; and the perception of koala population change. First, in order to compare the distribution of koalas in 1990 with the 2006–11 surveys, we needed to take account of the difference in number of respondents in the two surveys (i.e. survey effort). We therefore sampled the 1990 survey results to match the number of respondents in the 2006–11 survey (i.e. 265 respondents). For the comparison, we randomly sampled 265 respondents from the 1990 survey and counted the number of koalas observed in each 1-km^2 cell. We then compared these data to the 2006–11 survey results with each cell classified as increasing, decreasing, no change, or no data, when comparing the number of koalas observed in each period. We repeated the random sampling, comparison and classification 500 times and compared the average number of cells in each of the four classifications. Equal numbers of cells showing an increase or decrease indicates no significant difference in the distribution of koala sightings in the two survey periods.

In addition to the distribution of koalas, we also looked at an index of koala population size, namely the number of koalas recorded per respondent. Citizen science projects, such as this one, which use questionnaires of community members, can be spatially biased towards where the human population occurs. Within Coffs Harbour, most of the human population occurs in the south-east of the LGA (Fig. 1). In order to compare the survey results from the 1990 survey within the 2006–11 survey, independent of the density of human population, we presented the survey result as the number of koalas observed per respondent in each 1-km^2 cell. Using a paired *t*-test, and only including those cells that had data in both survey periods, we compared the number of koalas observed per respondent in the two survey periods.

In the 1990 and 2006 surveys, respondents were asked for their perception of whether the koala population in their local area was increasing, decreasing or staying the same (Predavec *et al*. in press). Respondents were also asked if they had seen koalas with back young (as evidence of reproduction in the population) and if they had seen sick koalas (specifically, koalas with a wet bottom or pink eyes as evidence of the disease *Chlamydia* in the population). The distributions of responses in the various categories and from the two periods were compared using Chi-square tests.

Field plots

Compared with the community surveys, field-based surveys provide a systematic sampling strategy for assessing current habitat preferences of koalas that is unbiased by proximity to roads or areas of human concentration where people's observations are more frequent. The use of a second, independent survey method was recognised as an important element of preparing a habitat map and CKPoM (Department of Planning 1995; Lunney *et al*. 1997) and was used in the preparation of the original plan (Lunney *et al*. 1999*b*).

We searched for both koala presence and koala scats (i.e. faeces or dung in the form of distinctive pellets) during the field-based survey. Koala scats generally persist in the environment well after the koala has left the site and are therefore a useful indicator of habitat use by koalas, but we are well aware that the scats decay at different rates in different habitats (Rhodes *et al*. 2011*a*). This survey method is particularly important in an area where koalas are in low numbers and in dense or closed forests (such as in Coffs Harbour) where they are often hard to see.

Originally, 119 sites were selected as part of the preparation of the CKPoM, based on vegetation communities (map units) and stratified, when appropriate, by geology, aspect and topography (e.g. ridge, slope, gully). Details are presented in Lunney *et al*. (2000*a*) and Lunney *et al.* (1999*b*). At each site, we randomly selected and marked out a 20 × 20 m quadrat. For each tree, in each quadrat, we recorded the following attributes: tree species, diameter at breast height over bark (DBHOB), koala present/absent, presence/absence of koala scat in a 1-m radius around the base of each tree, presence/absence of koala scat in a 1 × 1 m quadrat located haphazardly under the canopy of the tree.

As in Phillips *et al*. (2000), a tree was defined as any live woody stem of any plant species (except palms, cycads, tree ferns and grass trees) with a DBHOB of at least 10 cm. Searches for koala scats involved a thorough examination of the leaf litter, with a sample of koala scats from each positive quadrat collected and retained for verification. Trees were classified as active if there was evidence of koalas (i.e. either a koala present or one or more koala scats recorded), or inactive. We calculated the activity of koalas for each quadrat as the number of trees within the quadrat that had koala scats underneath.

The 119 sites originally surveyed for koalas in 1996 covered 42 different vegetation types (map units) with a total of 2458 trees sampled (Lunney *et al*. 1999*a*). In 2011, the same sites (or within 100 m, that being the limit of accuracy of mapping in 1996) were resampled. Access could not be gained to some of the sites and only 89 sites were resampled, containing a total of 1666 trees. Consistency between 1996 and 2011 was maximised because the same person (Mark Fisher) undertook the field surveys in both periods.

We compared koala activity in field plots in 1996 with 2011 using a model of the form:

$$N_{i,1996} \sim \text{binomial}(p_{i,1996}, T_{i,1996})$$

$$N_{i,2011} \sim \text{binomial}(p_{i,2011}, T_{i,2011})$$

where $N_{i,1996}$ is the number of active trees at site i in 1996, $N_{i,2011}$ is the number of active trees at site i in 2011, $T_{i,1996}$ is the number of trees searched at site i in 1996, $T_{i,2011}$ is the number of trees searched at site i in 2011, $p_{i,1996} = \exp(a_i)/(1 + \exp(a_i))$ is the probability of finding an active tree at site i in 1996, and $p_{i,2011} = \exp(a_i + b)/(1 + \exp(a_i + b))$ is the probability of finding an active tree at site i in 2011. Here the parameter b is the change in the probability of finding an active tree between 1996 and 2011 averaged across all sites. To test for a significant change in probability of finding an active tree between 1996 and 2011 we fitted the above model in JAGS (http://mcmc-jags.sourceforge.net/) with uninformative normal priors for a_i and b and identified whether the 95% credible interval for b contained zero or not.

Wildlife carer data

We also looked at koala records held by the NSW Wildlife Information, Rescue and Education Service (WIRES). WIRES has a high profile in the Coffs Harbour community, and is the main recipient of reports from the public of local koala sightings, particularly of koalas with a problem of some kind. In the Coffs Harbour region, WIRES records all information on injured and rescued koalas reported to them, whether or not there is any intervention. These data include location, life stage of the animal, known cause of problem, and fate. WIRES' record-keeping system effectively functions as a continuous, real-time community survey for koalas, driven by actual koala sightings rather than by direct survey, although it is incomplete to the extent that an unknown proportion of the community's koala sightings go unreported. Nevertheless, the sheer size (2240 records provided to this study) and detail of WIRES' koala data, including injury, threat of injury (i.e. unsafe location) and disease, can point to changes in the magnitude and spatial distribution of threats to koalas (e.g. Moon 1995). By themselves, these data may be hard to interpret in terms of changes in population. In this study, we used the data to provide further information that may support the population patterns shown in the community and field surveys as well as providing information on possible changes in threats. WIRES' data on koalas in the Coffs Harbour Region had previously been compiled for two periods (1990–95 [6 years] and 1999–2003 [5 years] for another purpose, and to these we added data for the period 2005–13 [8.25 years]). We completed a comparison of the number of animals reported per year in the three periods because of dogs, vehicle strike and disease, three known major threats for koalas (Natural Resource Management Ministerial Council 2009). Information on location allowed us to assign the koalas to one of the same 12 local areas used in the original community survey in 1990. We mapped these data in order to allow visual comparison.

Results

Community survey data – general

Data from the 1990 community survey identified that koala sightings were widespread throughout the study area (Fig. 2). As was expected with a community-based survey, a higher density of records corresponded with a higher human population density: in this case in the south-east of the LGA and on the coast. Similar patterns were seen in the 2006–11 data (Fig. 2), although the survey returns were much smaller than in 1990.

Randomly sampling the 1990 data and plotting the Area of Occupancy against the sample size (Fig. 3) confirms that the Area of Occupancy is a factor of the sample size and that, in this case, the curve does not level off. The curve is expected to level off when the full distribution of koalas is recorded, with subsequent records not adding to the Area of Occupancy. However, with a sampling method that is spatially clumped (in this case in the south-east of the study area) a very large sample size would be required in order to fully sample the true Area of Occupancy. The 1990 data do not, therefore, represent the likely full distribution of koalas within the study area, but they do represent a solid base with which to make comparisons with other periods, and hence determine changes in the distribution of koalas. The 2006–11 data fit on the 1990 resampled curve (Fig. 3).

Community survey data – pre-1990 recollections

In 1990 respondents were asked how long they had lived in the local area and to indicate the year in which they saw the koalas they were recording. While the raw data show an increase in the number of koalas seen per respondent between 1981 and 1990 (Fig. 4), they do not account for the forgetfulness of people. Forgetting is especially likely in this instance given that not only

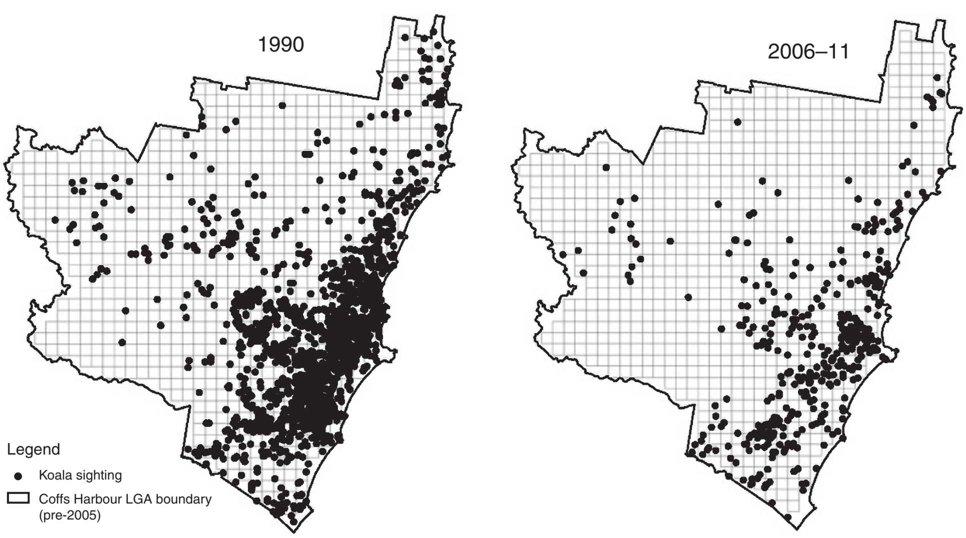

Fig. 2. Koala sightings from the 1990 and 2006–11 community surveys. Each grid cell is 1 km^2.

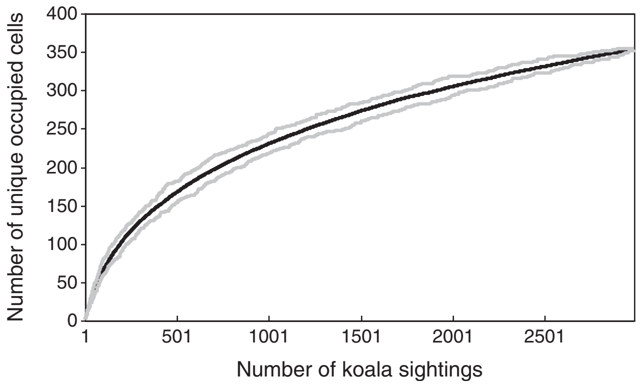

Fig. 3. The relationship between survey effort (number of koala sightings) and the area of occupancy. Data are the mean number of unique 1-km^2 cells (Area of Occupancy) resulting from a random sample of koala sightings in the 1990 Community Survey dataset. Data are means, with the range of values shown. $n = 50$ repeat samples for each sample size.

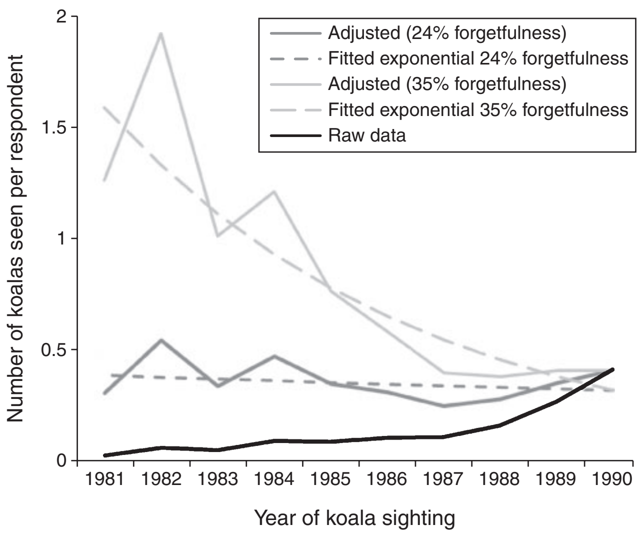

Fig. 4. Change in the number of koalas seen per respondent over the period 1981–90. Data have been adjusted on the basis of two forgetting curves (35% and 24%).

Table 1. The number of cells with koala observations and the change in observations comparing 1990 and 2006–11 survey data

1990 data were downsampled to 265 respondents in order to match the survey effort of the 2006–11 survey. Data are the average of 500 repeat samples

	Average	Minimum	Maximum	Lower 95% CI	Upper 95% CI
No data	597.1	575	619	596.3	597.8
No change	23.6	12	37	23.2	24.0
Increase	118.8	103	135	118.4	119.2
Decrease	114.6	94	146	113.7	115.4

were we asking for the year, but also the location, because that question was map-based (Lunney *et al.* 1999*b*). Fitting a curve based on the calculated maximum rate of forgetfulness (35%) reverses the overall trend and the rate of observation of koalas decreases at a rate of 15% per year between 1981 and 1990. When we adjusted the data based on the five-year average rate of forgetfulness (24%), the fitted curve showed a decline in the rate of koalas observed per respondent of 2% per year. Therefore, these data identify a decline in the rate of koala observation of between 2 and 15% per year in the period 1981–90 (Fig. 4).

Community survey data – change in koala distribution

Comparing the down-sampled 1990 survey data with the smaller 2006–11 survey data (Fig. 5) showed there was no difference in the distribution of koalas, with any observed differences before downsizing the 1990 data due to the differences in survey effort between the two surveys. Once the survey effort is accounted for, then there is no difference, with a similar number of grid cells showing an increase in koala sightings as those showing a decrease (Table 1), indicating no overall change in the sampled distribution of koalas between 1990 and 2011.

Community survey data – change in koalas sighted per respondent

The number of koalas sighted per respondent (Fig. 6) indicates that there is a higher density of koala sightings in the south-east of the LGA compared with the rest of the LGA. This pattern is consistent in both the 1990 and 2006–11 surveys. Of the 142 cells that had koala sightings in both survey periods, 61 cells showed no change in the number of koalas seen per respondent, 17 cells showed an increase and 62 cells showed a decrease. Overall, the data show a small, yet statistically significant, decrease in the average number of koalas seen per respondent ($t = 2.99$, $P < 0.005$). In the 2006–11 survey there was one fewer koala observed for every 10 respondents compared with the 1990 survey (a decline of 0.1 koalas per respondent). This equates to an average decline across the cells sampled of 4%, although these numbers are constrained to only those cells where koalas were observed in both periods.

Community survey data – perceptions of koala population change

In 1990, 474 respondents had an opinion on the direction of population change in koalas (Table 2). Many respondents (60%) thought that the koala population in their local area was decreasing at the time of survey. In total, 33% of respondents thought the population was stable and only 7% of respondents thought that the population was increasing. In 2006, 150 respondents had an opinion on the population change. Only 7% of the 2006 respondents thought there was an increasing population, the same percentage as in 1990. However, in 2006 the highest proportion (49%) thought the population was stable and 45% thought the population was decreasing. The distribution of responses in the three categories comparing 1990 to 2006 is dependent on year (Table 2, $\chi^2 = 17.0$, $P < 0.001$). The proportion of koalas seen with young decreased in the 2006–11 survey compared with the 1990 survey from 25% to 19% and this is dependent on year (Table 2, $\chi^2 = 7.1$, $P < 0.05$). Although there was a small increase in the proportion of sick koalas seen in 2006 compared with 1990, the distribution is independent of year (Table 2, $\chi^2 = 2.0$, $P > 0.05$).

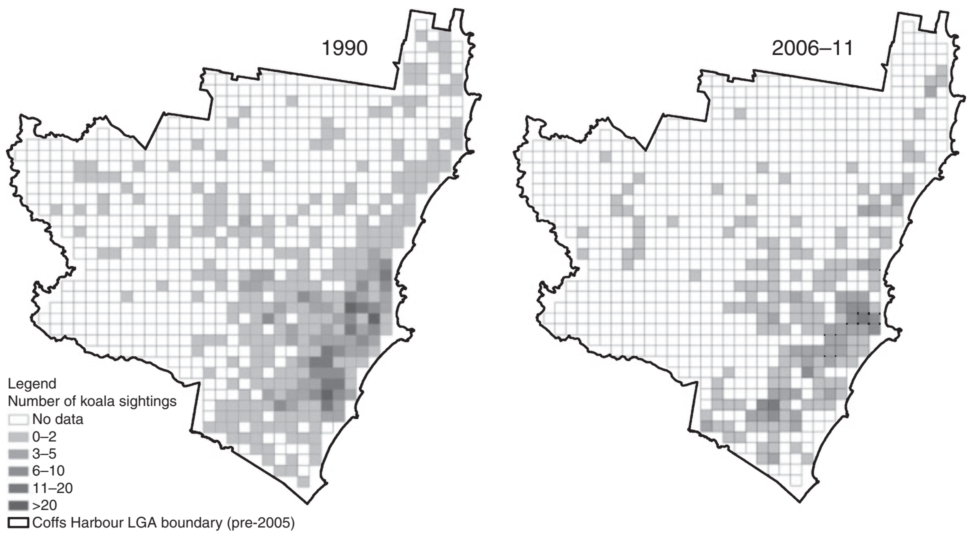

Fig. 5. Koala sightings per cell in 1990 (downsampled and average of 500 runs) and 2006–11, presenting a picture of the distribution of koalas in the two periods. Each cell is 1 km^2.

Field plots

Visual comparison with the field plot data and koala activity (Fig. 7) shows little koala activity in the north of the study area in 1996, with that pattern persisting in 2011. The comparison of the measures of koala activity from the two survey periods across the 89 sites showed 46 sites with no change in koala activity, 21 sites with a decrease in koala activity, and 22 sites with an increase in activity, as shown by the proportion of tree with scats. The average change in activity across the 89 sites was 0.001. There was no significant difference in koala activity comparing field plots in 1996 with the same plots in 2011 (95% credible interval for b change parameter = –0.33 to 0.31). The field plot data (Fig. 7) which, unlike the community survey data, are not related to the distribution of the human population, show that koala activity is concentrated in the south-east of the study area. We conclude that the distribution of koalas within Coffs Harbour is focussed on the south-east of the LGA where the human population is also concentrated. We also conclude that the spatial distribution of the community survey records (Figs 3 and 6) is not simply an artefact of the survey method, but it reflects the actual distribution of koalas within the LGA.

WIRES koala records

The number of koalas reported to WIRES each year because of three recognised threats (disease, injury from dogs, and injury from vehicles) increased in the period 1999–2003 compared with the earlier period 1990–95 (Fig. 8). The proportions of koalas in each threat category are dependent on the period ($\chi^2 = 10.1$, $P < 0.01$) with the increase due largely to the number of animals reported as a result of disease. Although there is a reduction in the overall number of koalas in these threat categories reported to WIRES in the period 2005–13 (Fig. 8), the high proportion of sick animals remains from the earlier period, and the pattern is independent of the period ($\chi^2 = 0.6$, $P > 0.05$).

The spatial distribution of koalas reported to WIRES (Fig. 9) shows that disease was the major cause of koalas being reported, and that most of the animals came from the south-east of the study area. The data cannot distinguish whether this pattern was the result of more koalas in the area or a greater number of people, or indeed a higher proportion of koalas succumbing to threats. It is revealing to note that no koalas were reported for any of the three threats in the north-eastern local area, despite there being a high density of people (Fig. 9). This allows us to surmise that the number of koalas in each local area is contributing to the overall pattern observed (i.e. that higher numbers of koalas go into care in areas where higher numbers of koalas exist).

Discussion

The data presented and analysed in this study show that the koala population in Coffs Harbour has endured over the last 25 years and that it appears, surprisingly, to be relatively stable. This conclusion comes from three independent survey methods (community survey, field survey, WIRES records) and four approaches to analysing the data. All approaches show similar and consistent patterns of no, or only small, change. The number of koalas sighted per survey respondent showed a decline between the two time periods, but the rate is modest (4% over 21 years). Although we did not directly compare the results of the community survey with those from the field surveys, visually they show the same pattern and allow us to demonstrate the endurance of this pattern from 1990 to 2011, with surveys in 1996 and 2006 falling in between. While the primary output of the survey methods is the distribution of koalas, the number of koalas observed per respondent, and the activity levels from field plots, provide an index of population numbers that can be monitored through time. The results indicate no change in the distribution of koalas within the sampled area and, at the same time, only a small decrease in koala activity as shown by the number of animals observed per respondent.

Although the broad study area for this work is the Coffs Harbour LGA (Fig. 1), we note that the community surveys are, by their nature, biased towards private lands and towards where

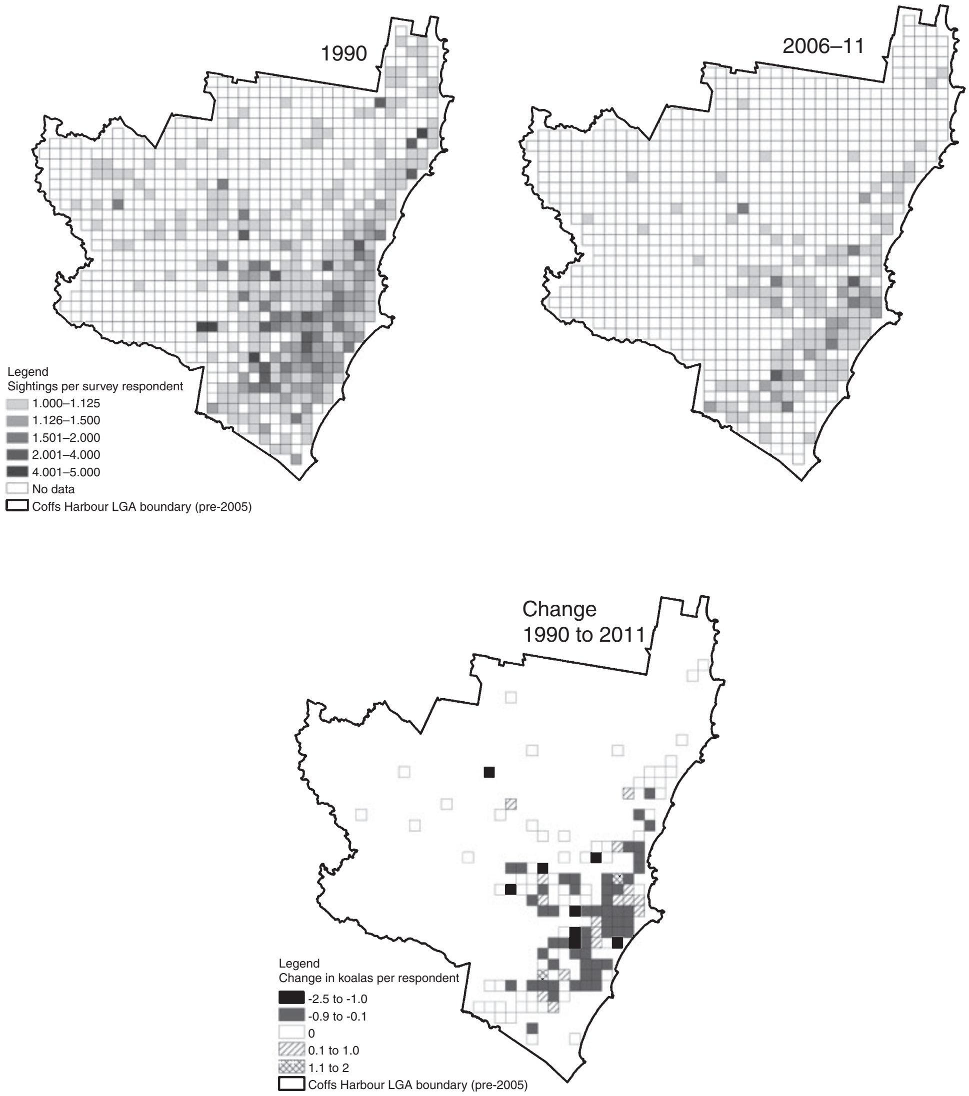

Fig. 6. Number of koala sightings per respondent (1990 and 2006–11) and change in the number between the two periods. Each cell is 1 km^2.

Table 2. Community survey responses to direct questions regarding the koala population in Coffs Harbour
**, $P < 0.05$; ***, $P < 0.001$; n.s., not significant at $P = 0.05$

Period	Question and response			χ^2	*P*
Is the koala population in your area increasing, decreasing or staying the same?					
	Increasing	Decreasing	Staying the same		
1990	34 (7%)	285 (60%)	155 (33%)	17.0	***
2006	10 (7%)	67 (45%)	73 (49%)		
Have you seen koalas with back young in your local area?					
	Seen koalas with young	Not seen koalas with young			
1990	217 (25%)	639 (75%)		7.1	**
2006	36 (19%)	157 (81%)			
Did any of the koalas you saw appear to be unhealthy (for example, have weeping or pink eyes or discoloured bottoms)?					
	Seen a sick koala	Not seen a sick koala			
1990	115 (13%)	741 (87%)		2.0	n.s.
2006	30 (16%)	152 (84%)			

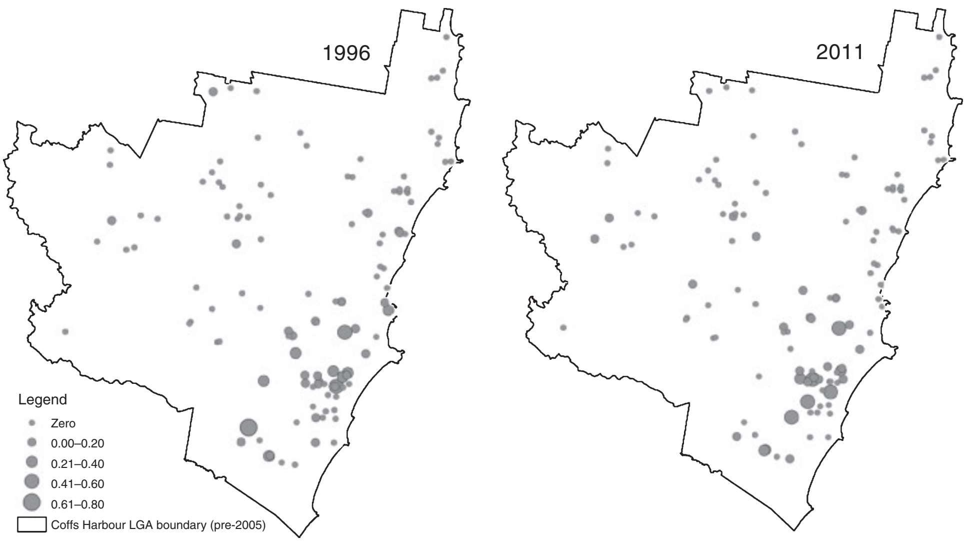

Fig. 7. Field plot data from 1996 and 2011 showing survey sites with the level of koala activity shown by the size of the point. The activity levels in the legend are the proportion of trees within the plot with signs of koala activity.

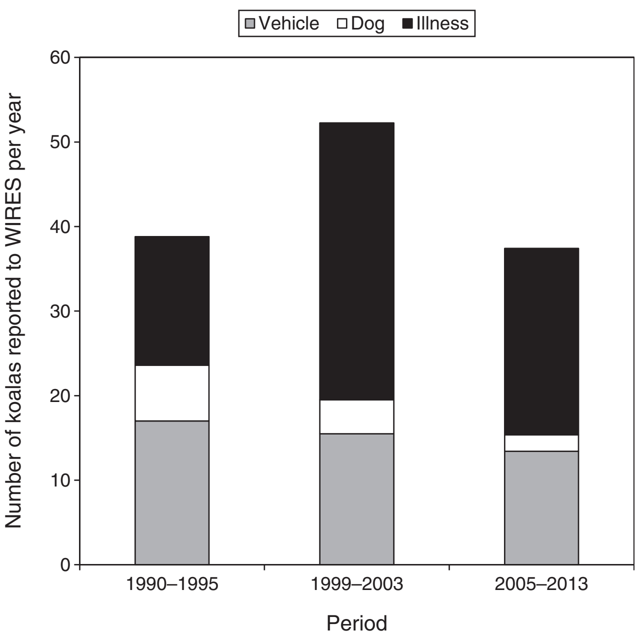

Fig. 8. Number of koalas reported to WIRES per year across three major threat categories. (Source: WIRES Mid-North Coast.)

the human population is located. Similarly, the initial field survey sites were chosen to be located on private or Council-managed lands since they were intended to inform preparation of the CKPoM (Lunney *et al*. 1999*b*), which related only to these tenures. This means that the community survey results are skewed towards the south-east of the LGA where there is the highest density of human population (Fig. 9) and where the most private land occurs (Fig. 1). The pattern resulting from the field survey, however, allows the conclusion to be drawn that the distributions shown in the community surveys are not merely the result of more people making observations, but also include an underlying higher activity of koalas in the south-east of the LGA (Fig. 6). It is noteworthy that the human and koala population appear to favour similar broad habitats (highly fertile, coastal lands) and this makes the survival of koalas in this area even more surprising. While our results focus largely on the coastal areas of the LGA, and within private lands, broad areas of State Forests in the west of the LGA contain few community survey data and therefore little can be said about these areas in this study. The fourth approach to determining population change was to ask community survey respondents their perception of the trajectory of the koala population in their local area (c.f. Predavec *et al*. in press). This showed a pattern consistent with a population that is stable, or slowly declining, between 1990 and 2006, following a more noticeable decline before 1990. In 1990, the highest proportion of respondents thought the koala population was declining, whereas in 2006, the highest proportion thought that it was staying the same. These data are consistent with the pattern of decline shown in the 1980s and together suggest that the major decline in the koala population of Coffs Harbour occurred before the start of our survey in 1990.

In the absence of a structured and robust monitoring program for koalas over the period in question, the use of multiple independent methods of assessing change is important. This was recognised in the preparation of the initial CKPoM (Lunney *et al*. 1997), where two independent methods were used, and still holds today. With three survey methods, and the four approaches showing a similar pattern in the Coffs Harbour koala population, we should be confident that the population has been relatively steady and enduring between 1990 and 2011. However, we report our conclusions with a certain sense of unease. From our own detailed knowledge spanning 25 years, across the whole LGA and adjoining districts, our perception is one of an inexorable decline of local koalas. This perception is shared by most of our local koala-aware contacts, such as WIRES koala co-ordinators, NPWS staff, many landowners and in fact

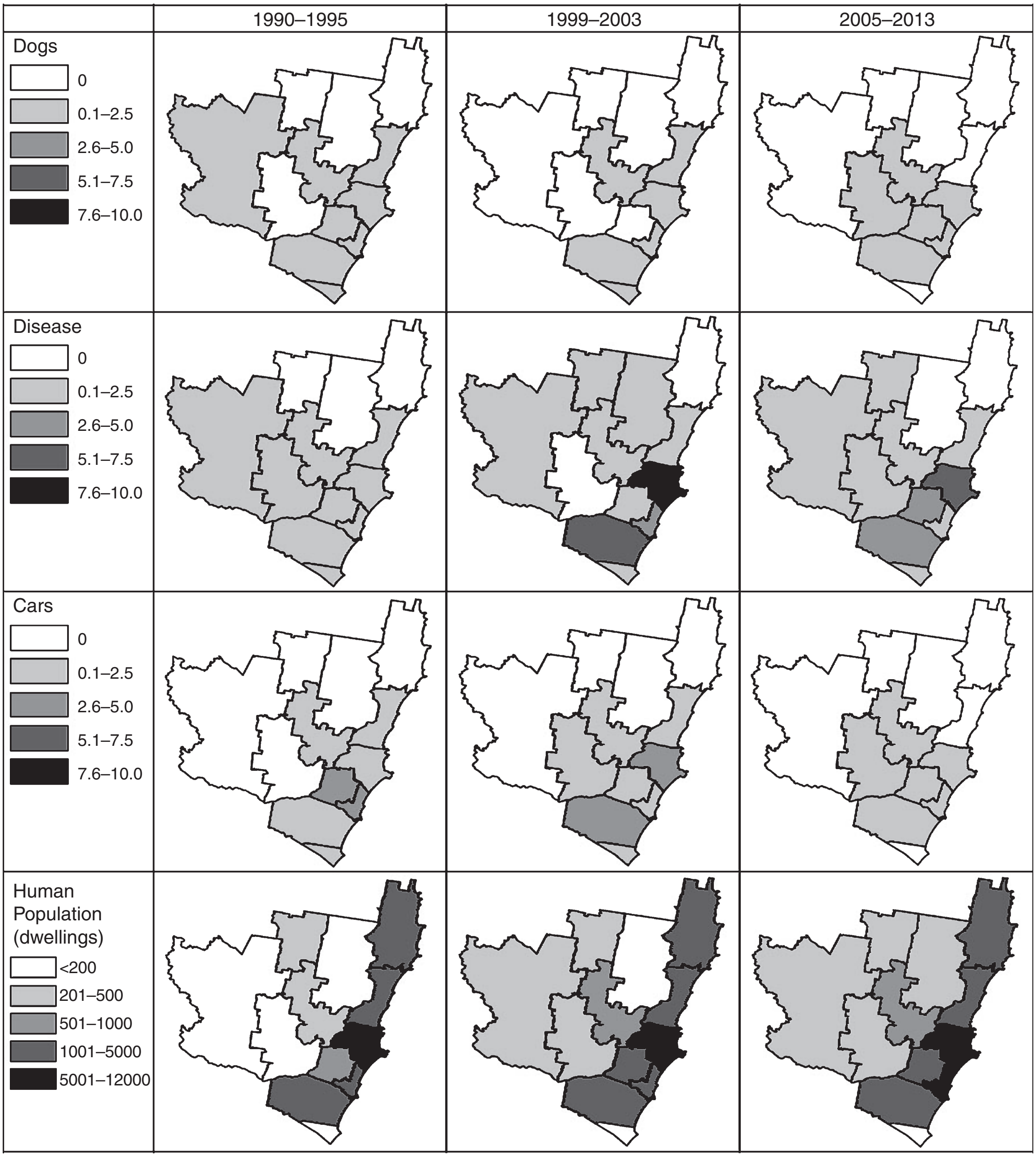

Fig. 9. Spatial distribution of koalas reported to WIRES over three periods as a result of three recognised threats: dogs, cars and disease (Source: WIRES Mid-North Coast.) Data are expressed as the number of koalas per year across 12 local areas within the Coffs Harbour LGA. The spatial distribution of the human population is provided for reference.

nearly 50% of respondents in the 2006 community survey (Table 2). Stability also seems counter-intuitive, given the very high attrition rate, as shown in the WIRES records, remembering that these data only include koala losses that have been both noticed by someone and reported to WIRES. Such a conclusion appears also to contradict the accepted understanding of recent koala population declines of the north coast of NSW, including Coffs Harbour (e.g. Scotts 2013; McAlpine *et al*. 2015).

These results do not mean that a decline in the Coffs Harbour koala population has not occurred, but rather that it does not appear to have occurred in a dramatic manner since 1990. Lunney *et al*. (2015) propose that the koala population of Coffs Harbour was never high. This is supported by a lack of significant fur trade in the region at times when other parts of NSW and Queensland were subject to significant hunting pressure and the monetary value of skins was high. It is further supported by the general lack of records in the local media. While this historical work does not have the data or resolution to detect a change in numbers, it can be assumed that the loss of habitat (initially from clearing for agriculture and logging and more recently through urban development and associated infrastructure) will have resulted in a reduction in the koala population. These changes are likely to have occurred in the late 19th and early 20th century in the case of logging and in the 1970s and 1980s in terms of rapid urban development – both before the initial community survey of 1990. This historical pattern fits with the pattern of dramatic population decrease shown by the number of koalas seen per respondent, when corrected for forgetfulness of respondents (1980 to 1990).

Hypotheses to explain a stable koala population in Coffs Harbour

Given the finding of an apparently stable koala population, it is relevant to ask why this is so, when other populations clearly appear to be in rapid decline. Here we discuss four possible explanations although they are by no means mutually exclusive. The first possible explanation is that conservation efforts and planning regulations in place have been effective. The koala has a significant body of legislative protection, policies and plans aimed at it (Table 3), yet these generally occur across NSW, including in areas where population declines have occurred. The distinguishing protective measure in place for Coffs Harbour is the CKPoM and the length of time that the plan has been in place. The plan was completed and placed on public exhibition in 1998 and approved by the Minister for Planning in 2000. The primary aim of the plan, as stated in 1999, is to 'provide a framework for the conservation and management of koala habitat, and the management of threats to koalas, to ensure permanent free-living populations over their present range in Coffs Harbour LGA, and reverse the current trend of koala population decline' (Lunney *et al*. 1999*b*). Given that all of the authors of the original CKPoM are also authors of this paper, it is tempting to say that the plan has been a success in that since 1990 there does not appear to have been a dramatic population decline in Coffs Harbour. However, several points suggest that the CKPoM may not be the (only) driving force behind the stable koala population. First, the plan was implemented in 2000, almost halfway through the stable population period identified in this study. Our results demonstrate that the stable pattern seen in the Coffs Harbour koala population was occurring both before and after the CKPoM was endorsed. Second, a review of implementation of the CKPoM (EcoLogical Australia 2006) concluded that the plan has been only partially implemented by Council. For example, of the 245 ha of koala habitat that was cleared in Coffs Harbour between 2000 and 2005, 30 ha were primary koala habitat (EcoLogical Australia 2006). Finally, three of the threats that are significant to koalas (dogs, cars and disease) appear to be stable during the time that the plan has been operating. Within a stable population, this supports the idea that threats have also remained stable and that the plan has not been effective in managing or reducing their impact. While the relationship between the CKPoM and the koala population is not directly clear, the plan and the associated works have raised the profile of the koala in the LGA within the broad community, and this would certainly be important in any conservation effort.

The second possible explanation is that we are looking at a relatively low-density population that has suffered declines in the past through the loss of habitat, but in which adults have established stable home ranges and are able to persist in the area. The historical loss of habitat in the south-east of Coffs Harbour has not been broad-scale. There remains in the south-east a matrix of what has been identified as primary koala habitat in the CKPoM. If this matrix is sufficient to support a population, then the population should be able to persist with the population density determined by the amount of available habitat. Detailed studies of the koala populations adjacent to the Pacific Highway during two upgrades (at Lindsays Cutting and Bonville) demonstrate this persistence in the south-east of Coffs Harbour. Radio-tracking studies before, during and after construction (Lassau *et al*. 2008) showed that koalas had established home ranges that bordered the existing highway, but that crossings of the barrier were infrequent. Road deaths peaked in September and October, and were attributed to young, dispersing animals or older displaced individuals attempting to cross the highway. Realignment of the highway did affect some resident animals with home ranges crossing the alignment, but following construction (and barrier-fencing) the remaining animals adjusted their home ranges to match the new alignment (Lassau *et al*. 2008).

The third possible explanation is that the broader Coffs Harbour population is operating as a source and sink metapopulation with higher-density breeding populations providing a source of animals to the surrounding area where they may or may not breed. One possible source population is Bongil Bongil National Park in the south of the LGA. This national park is one of the few remaining coastal blocks of koala habitat and is known to support a strong population of koalas (Smith 2004). It is recognised as a potential source area for dispersers to adjoining subpopulations (Scotts 2013), and if this is indeed happening we would expect local koala

Table 3. Legislation and plans relevant to conservation of koalas within Coffs Harbour

Level	Legislation	Policy	Plans
National	*Environment Protection and Biodiversity Conservation Act 1999* – Vulnerable (2012)	Koala referral advice for proponents	National Koala Conservation and Management Strategy (2009–14)
State (NSW)	*Threatened Species Conservation Act 1995* – Vulnerable (1995) *Environmental Planning and Assessment Act 1979* *Native Vegetation Act 2003* *Forestry Act 2012*	SEPP 44 – Koala habitat protection (1995)	Koala Recovery Plan (2008) Integrated Forestry Operations Approval (Upper North East) Private Native Forestry Code of Practice
Local (Coffs Harbour)			Comprehensive Koala Plan of Management (CKPoM)

sightings and road-kill records to reflect the presence of roaming koalas. While there are no specific data available on the movements of individuals between the national park and the koala-supporting urbanised environments that would support this proposal, WIRES records for the period 2005–13 contain 88 records of koalas in rural Bonville north of Bongil Bongil National Park, including along Lyons Road from Sawtell to the Pacific Highway, a number large enough to lend support to this possible explanation.

The final explanation is that the population is in fact declining, but at such a rate to make the decline almost imperceptible. The community survey and field plots methods used in this study did not demonstrate a change in distribution of koalas. However, there was a small, yet statistically significant, decline in the number of koalas reported per respondent (4% over 21 years). In the south-east of the LGA, where numbers of koalas are relatively high, such a small change may not be noticeable. However, in the north of the LGA, where koala numbers have been relatively low during the study (see Figs 6 and 8), such a small change may see koalas disappear from the local area, but again at such a rate as to be almost imperceptible. Such a pattern of decline, with the impact on the population being more apparent in the north of the LGA, is consistent with anecdotal evidence from koala experts in the LGA who suggest that koalas have become functionally extinct (i.e. not detectable using standard survey methods) in the north of the LGA. If such a gradual decline is happening, this has important consequences for how we monitor such koala populations. Field plots and, to a lesser extent, community surveys, are the primary means by which koala populations are surveyed in the preparation of a CKPoM (e.g. Department of Planning 1995) and are recommended as a means of monitoring population changes (e.g. Phillips and Callaghan 2011). This study has identified that these primary methods are not always sufficient to detect the subtleties of koala population change, and confirms the conclusions of earlier studies (cf. Rhodes *et al*. 2006).

Management implications

How do we manage an apparently stable population of the threatened koala into future conservation frameworks? Although the koala population of Coffs Harbour may be relatively stable, a range of recognised threats is still operating within the LGA. The number of animals reported or delivered to the local WIRES group each year is evidence for this view. It is unlikely that the situation will remain the same. The Coffs Harbour settlement strategy estimates that an additional 32 000 residents will live in the LGA by 2031 (Coffs Harbour City Council 2008), representing a 45% increase on current numbers. This will result in further vegetation and habitat clearing as well as increased risks from cars and dogs. While it is possible that koalas may be able to accommodate some of these changes, it is likely that the result will be a decrease in the population, as was seen in the 1980s, although from a much lower starting point. It may not take a large population change in the future to precipitate a rapid decline. Population viability analyses carried out in Port Stephens (Lunney *et al*. 2007) and the Iluka Peninsula (Lunney *et al*. 2002*b*) have shown that even small changes in the koala population structure can result in rapid population declines. Notwithstanding, a CKPoM is still a relevant document for Coffs Harbour. However, for the plan to be successful, we must better understand how the koalas endure in Coffs Harbour. The plan must also be better implemented and be tenure blind.

Our long-term datasets have enabled us to show an apparently enduring and stable population of koalas within Coffs Harbour, but in doing so we have highlighted shortcomings of the data collected to date. Better information on population numbers and dynamics and movement of individuals is needed in order to demonstrate the population patterns, and these data, along with citizen science and indirect surveys, should form the basis for future comparisons. Such additional data will allow us to start to unravel the complexity of the pattern of koala populations (for example, that koalas remain in areas of Coffs Harbour where the human population density, and associated threats, is highest). A worked example of a declining koala population in south-east Queensland identified the need to integrate multiple threats and data sources into population modelling (Rhodes *et al*. 2011*b*; Ng *et al*. 2014) and thereby provides a starting point for the next stage of research into resolving the causes of stability of koalas in Coffs Harbour. The Senate enquiry into the koala was struck by the complexity of the issue of koala conservation (Senate 2011). Coffs Harbour is a case in point, and strategies, actions and plans need to reflect that complexity. We need to deal with the ecological reality of why the koalas are enduring in Coffs Harbour, yet declining elsewhere, and that is proving to be a difficult task.

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