Koala Likelihood Mapping - Baseline Koala Survey Analysis and Reporting



Final Report to Environmental Protection Authority

24th June, 2016

(Updated & Revised 6th July, 2016)

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Citation:

Phillips. S., and Wallis, K. 2016. Koala Likelihood Mapping - Baseline Koala Survey Analysis and Reporting. Final Report to NSW Environment Protection Authority. Biolink Ecological Consultants.

Summary

This report examines aspects of the Koala Likelihood Mapping (KLM) project initiated by the NSW Office of Environment & Heritage on behalf of the NSW Environment Protection Authority. The KLM project is intended to provide a basis for informing natural resource management issues including the setting of prescriptive measures in the context of forestry operations. KLM comprises a series of 10 km grid cells covering NSW, with 5 km grid cells utilized in areas where data is abundant, at both scales forecasting the probability of koala likelihood relative to those of other arboreal mammal species in each of three confidence classes A (high), B (moderate) and C (low), *de facto* regarding records of arboreal mammals as units of observation effort. Ongoing refinement of the KLM is enabled through a dedicated Baseline Calculator Spreadsheet that adjusts cell confidence levels and koala probability estimates in response to the addition of new data.

The purpose of the Baseline Koala Survey Analysis and Reporting project was multi-faceted. Focusing on Koala Management Area 1 – North Coast, the KLM was further informed and updated by way of integrating available Wildlife Atlas and SAT data, secondly by undertaking habitat occupancy assessments within a series of KLM cells in order to fill data gaps and examine relationships between the KLM's probability parameters and field-based occupancy estimates for a series of cells in the highest confidence class, and lastly to consider such outcomes in a way that may assist further refinement of the KLM process and its intended application.

Two thousand one hundred and fifteen (2115) Wildlife Atlas records of arboreal mammals covering the time period March 2015 to Jan 2016 were available for uploading using the KLM Baseline Calculator Spreadsheet, 666 of which were of koalas. Koala presence/absence data from 1,784 SAT sites distributed across 11 Local Government Areas within KMA 1 from Port Stephens on the mid north coast of NSW to the Tweed LGA were also incorporated using the Baseline Calculator Spreadsheet. Collectively, these data resulted in changes to the confidence levels of 8 of the 503 10 km cells

that comprise KMA 1, including the upgrading of 4 cells to ‘A’ level confidence. At the finer level of resolution, changes to 58 of the 2065 5 km cells that comprise KMA 1 were affected, including the upgrading to ‘A’ confidence level of 23 cells formerly in lower confidence categories.

Field survey targeted the remaining 10 km cells for which no data was available, a sub-set of 10 km ‘C’ confidence level cells within which no koala records were known and a randomly selected series of 10 km ‘A’ confidence cells, the intent in the latter instance to examine any relationship between the associated KLM probability estimates of the likelihood of koala occurrence. Field survey was undertaken using a new methodology – Rapid-SAT – which was developed concurrently from a KMA-specific SAT database and designed to optimize detection rates and inform on koala absence in a more quantitative way by focusing survey effort on the most preferred koala food tree species, which for survey purposes were referred to as Designated Target Species (DTS).

Two hundred and sixty eight primary field sites were surveyed between Dungog in the south of KMA 1 and Tweed Heads in the north. Koala activity was recorded in 75 field sites. At the ‘A’ level of confidence koala occupancy rates estimates by field survey and the KLM cell-based probability of likelihood estimate were positively correlated, the level of which tended to be weakly significant at 10 km cell-scale but stronger at the 5 km cell-scale. This result offers some support for the relationship between koala records relative to those of other arboreal mammals as a useful measure of koala likelihood, while Rapid-SAT offers an alternative approach to data gathering, the nature of which appears generally compatible with KLM approach.

Further development and application of the KLM and Rapid-SAT approach will be contingent upon identification of DTS for each of the KMAs of interest for natural resource management purposes, and expedition of the progressive upgrading of cells at both 10 km and 5 km levels of resolution. Some qualification regarding application of the KLM is advocated in addition to recommendations regarding minimum cell-based survey effort and how the process of further KLM upgrades might be prioritized are also provided.

1. Introduction

The primary purpose of the Koala Likelihood Mapping Project in NSW was to create a means by which habitat areas of importance to contemporary koala populations could be identified. The project sought to do this by analyzing existing historical records of koalas so as to produce a "*Preliminary Map of the Likelihood of Koala Occurrence in NSW*" (hereafter referred to as the Koala Likelihood Map or KLM). The KLM is intended to provide a basis for informing natural resource management decisions including the setting of prescriptive measures in the context of forestry operations. Across New South Wales the KLM comprises a series of 10 km x 10 km grid cells, which are themselves comprised of 5 km grid cells in areas where data is abundant. Each cell forecasts the likelihood of koala occurrence relative to those of other arboreal mammal species, *de facto* regarding records of the latter as units of observation effort (Predavec 2015). Excluding cells which contain no records of arboreal mammals, three levels of "Confidence" are apportioned to grid cells: 'A' (high), 'B' (moderate) and 'C' (low), within each of which there are sliding scales of probability considered by Predavec *et al* (2014) to reflect the likelihood of koala occurrence. Thresholds between each of the levels are arbitrary but remain influenced by the amount of survey effort (measured as total numbers of arboreal mammal sightings) rather than the numbers of koala records. Ongoing refinement of the KLM is enabled through a dedicated Baseline Calculator Spreadsheet (BCS) that adjusts cell confidence levels and koala probability estimates in response to the addition of new data.

The Spot Assessment Technique (SAT) of Phillips and Callaghan (2011) was developed to provide a tool for assessing areas of forest woodland for evidence of koalas, the method relying on faecal pellet presence/absence data to index koala activity and enable identification of preferred food tree species. Regularised Grid-based SAT (RG-bSAT) sampling is now widely applied throughout eastern Australia for landscape-scale koala habitat and population assessments and is promoted by the Commonwealth Department of the Environment's *referral guidelines for the vulnerable koala* under the provisions of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) as an appropriate survey technique for investigating koala habitat use and occurrence (Anon 2014). The Biolink SAT/RG-bSAT database currently contains survey results from over 80,000 trees sampled from more than 2,750 field sites located throughout eastern Australia from East Gippsland in Victoria, through NSW and into south-eastern and central western Queensland. Other substantive SAT data sets are also maintained by the NSW Office of Environment & Heritage, the Australian Koala Foundation, tertiary research institutions and Landcare organisations.

The purpose of this project was multi-faceted; firstly to further inform and update the KLM by way of integrating available Wildlife Atlas and SAT data, secondly to undertake assessments within a series of KLM cells in order to fill data gaps and examine relationships between the model's probability parameters and field-based occupancy estimates, and lastly to consider such outcomes in a way that may assist further refinement of the KLM process and it's envisaged applications.

2. Methodology

Focal Area

The focal area for this project was Koala Management Area (KMA) 1 - North Coast as identified in Appendix 5 of the approved NSW Recovery Plan for the Koala (DECC 2008). Within NSW, the boundaries of KMA 1 (Figure 1) are defined by the geographic distribution of the preferred koala food tree Tallowwood *Eucalyptus microcorys* (Phillips 2000).

Informing Data

Atlas of NSW Wildlife

OEH Wildlife Atlas records for koalas and other arboreal mammals covering the period March 2015 – January 2016 were incorporated into the KLM Baseline Calculator Spreadsheet (BCS) developed by Predavec *et al*. (2014) for both 10 km and 5 km cell levels of resolution.

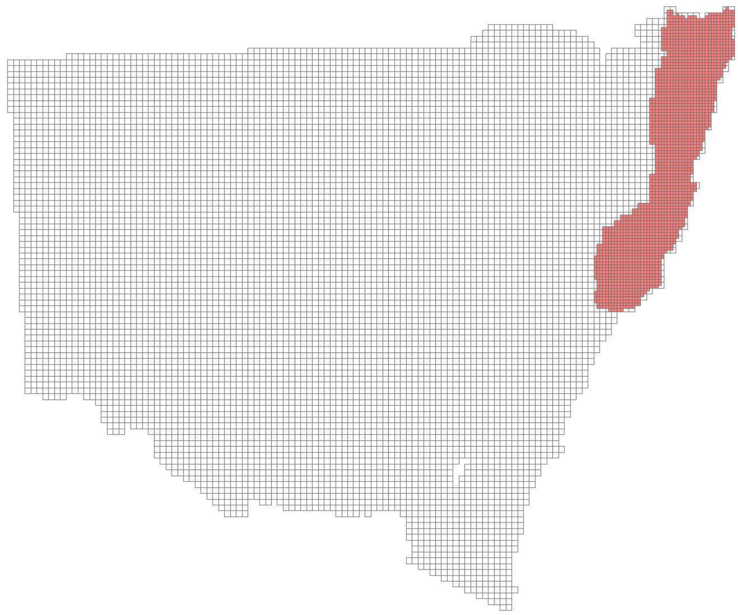

Figure 1. Location of Koala Management Area 1 – North Coast as illustrated in approved Recovery Plan for the Koala in NSW, here indicated by the red shaded 5 km x 5 km grid-cells utilized for the KLM project.

SAT Data

Site data relating to tree species/koala faecal pellet associations derived from SAT–based koala habitat assessment projects undertaken within KMA 1 were also processed through the KLM BCS for both 10 km and 5 km cell levels of resolution. For BCS purposes each SAT site was considered to qualify as an arboreal mammal survey, while SAT sites in which koala scats had been detected were deemed a koala observation.

Development of a rapid assessment survey methodology

The need to be able to rapidly assess areas for koalas required development of a new survey method. To this end we considered that the existing SAT database and associated sampling protocols offered the greatest potential for such a technique to be developed. To assist this process, SAT data from active sites within KMA 1 (*i.e*. field sites in which koala faecal pellets had been recorded) were pooled to develop a hierarchical tree preference table focused solely on the Genus *Eucalyptus*. In areas that are being utilized by koalas, *Eucalyptus* spp. with consistently high 'strike-rates' (*i.e.* percentage equivalent probability of one or more koala faecal pellets being recorded within 1 m from the tree base) are referred to as preferred koala food tree species and so offer the greatest chance of confirming koala presence/absence subject to considerations of appropriately informed survey design and sample size outcomes. Significantly, all preferred food tree species east of the Great Escarpment that return strike rates approximating 50% as assessed by SAT sampling protocols represent a finite resource for koalas given that such a strike rate can be readily demonstrated to reflect a measure of 100% utilization by the species.

To enable broad-scale application of the new survey method, all informing data was considered to have been obtained from a homogeneous landscape so as to avoid any complications arising from considerations of underlying soil fertility and its influence on food tree palatability and associated koala activity levels.

Decision Rules

In developing a rapid assessment methodology the following rule set was considered desirable:

(*i*) The tree species informing development of the technique should be widespread throughout KMA 1 and thus likely to be encountered in the course of a KMA-scaled field-based assessment.

(*ii*) The sampling protocol should be based on prior knowledge regarding those tree species that overall offer the highest probability of confirming koala presence.

(*iii*) The level of confidence in both the informing data set and the outcomes of a given survey event must be statistically defensible.
(*iv*) The sampling protocol should be based on a survey design that is capable of efficiently covering the site or area being assessed, preferably by way of an evenly distributed array of field sites at regularly spaced intervals, rather than by stratification, and
(*v*) Any method should be unambiguous and adaptable to a variety of situations given considerations of forest/woodland cover, access and the type of information/data that is required.

Application of Decision Rules

In order to qualify for consideration, tree species constituting the informing data set should ideally be represented by a minimum of 3 independent data sets, one each of which must ideally be located within the lower (Hunter – Hastings), mid (Hastings – Clarence), and far north coast (Clarence - Tweed) river catchments respectively, while also being collectively represented by a parametrically distributed data set such that np and $n(1 - p)$ must be ≥ 25[1] where n is the sample size, p is the strike rate (or estimated probability of finding one or more koala faecal pellets within 1 m of the base) and q is $1-p$.

Based on a *post hoc* analysis which indicated no significant difference between the relative proportions of active sites detected at 500 m or 1 km intervals when sampling for evidence of naturally occurring, low density koala populations in the south-east forests of NSW respectively (S.Phillips, unpub. data based on data reported in Allen *et al*. 2010), sampling intensity should ideally be scalable down to no less than 1 survey site 100 ha^{-1}.

Survey design should focus only on those tree species with the highest probability of having koala faecal pellets associated with them, the opposing failure to detect faecal pellets beneath an appropriately sized sample of such species obtained by way of an area-constrained, replicated sampling protocol thus being the best estimator of koala absence.

[1] Determined by expansion of the binomial term $(p + q)^n$ for a range of fixed probabilities as the minimum required to ensure an approximately normal distribution for appropriately collected data sets within the range of strike-rates known to occur across KMA 1.

In areas being utilized by resident populations of koalas, the presence of preferred food tree species influences the use of other non-food tree species that grow in close proximity (Phillips *et al*. 2000; Mathews *et al*. 2007). Because of this and once the most preferred trees species were identified, all informing field sites containing these species were removed and the remaining data re-examined to potentially identify any other tree species that were the subject of preferential utilization by koalas in the absence of the most preferred species.

Field survey

Following the updating of the KLM using Atlas and SAT data, survey work employing the Rapid-SAT approach outlined in Appendix 2 was directed to all remaining[2] 10 km x 10 km 'No data' cells and a randomly selected proportion of the sub-set of 10 km x 10 km 'C' cells wherein koalas had not been recorded, the intent in both instances to investigate the likelihood of koalas being present. At the higher end of the KLM confidence spectrum, a randomly selected sub-set comprising a series of "A" confidence cells reflective of the probability distribution for this level of KLM classification were also surveyed.

Survey design recognized the presence of four constituent 5 km x 5 km cells in each of the aforementioned 10 km x 10 km cells, regarding each of these smaller cells as spatially independent sampling units for the purposes of any analyses.

Quantitative point-based sampling of tallest stratum species using the cardinal – intermediate compass point approach developed for the Port Macquarie Hastings Vegetation Mapping Project (Phillips *et al.* 2013) was also incorporated into the assessment process for each site.

For KLM purposes, each primary Rapid-SAT field site was considered to comprise an arboreal mammal survey independently of the number of trees that were assessed at each site. Koala occupancy estimates for each grid cell

[2] This process excluded some coastal 'no data' cells that were predominantly water.

were estimated as the proportion of primary Rapid-SAT sites in which koala faecal pellets had been recorded.

Data Management & Analysis

All spatial data for the project was supplied by the EPA and managed using ArcGIS 9.3. KLM baseline data was supplied in Lambert projection which necessitated some transformations for both data integration and field survey purposes. The “A” confidence class cell selection for field assessment purposes was undertaken using the random selection options available in the Geospatial Modelling Environment (Beyer - Spatial Ecology LLE, 2012) application.

A T-test was used to compare DST live-stem densities in sites where koala faecal pellets were recorded, and where they were not. Relationships between KLM probability estimates (p) for the sampled series of A class cells and occupancy measures derived from field survey using Rapid-SAT were examined using the non-parametric Spearman Rank and regression informed, Pearson product-moment correlation coefficients.

3. Results

Supporting/Informing Data

Atlas of NSW Wildlife

Two thousand one hundred and fifteen (2115) arboreal mammal records covering the time period March 2015 to January 2016 were available for uploading into the KLM, 666 of which were of koalas. Seven hundred and fifty eight (758) of the preceding records related to KMA 1, 546 of which were of koalas. An example of the distribution of Atlas records across a proportion of the initial KLM baseline mapping layer within KMA 1 is illustrated in Figure 2.

SAT Data

Koala presence/absence data from 1,784 SAT sites distributed across 11 Local Government Areas within KMA 1 from Port Stephens on the mid north coast of NSW to the Tweed LGA over the time period 1995 – 2015 were available for incorporation (Appendix 1). Six hundred and ninety one of these sites contained evidence of koalas in the form of diagnostic koala faecal pellets. Figure 3 illustrates the distribution of SAT sites across the same proportion of KLM baseline layer as utilized in Figure 2.

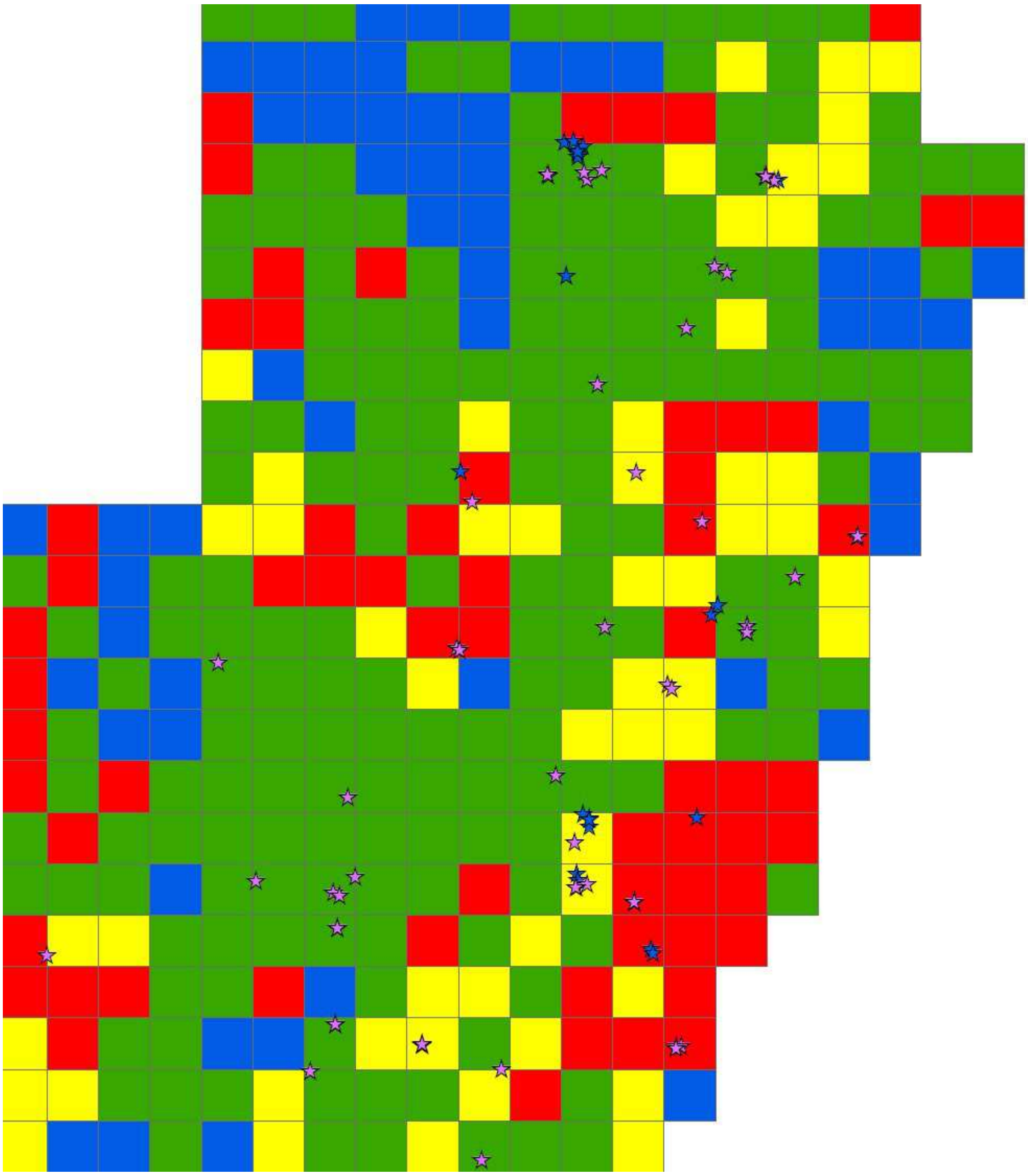

Figure 2. Distribution of NSW Wildlife Atlas records of koalas (pink stars) alongside those of other arboreal mammals (blue stars) for period March 2015 to January 2016 across the general area of the Port Macquarie Hastings LGA within KMA 1 (Records supplied by EPA). KLM baseline confidence categories for underlying 5 km cells are as follows: Red = 'A', yellow = 'B', green = 'C' and blue = 'no data'.

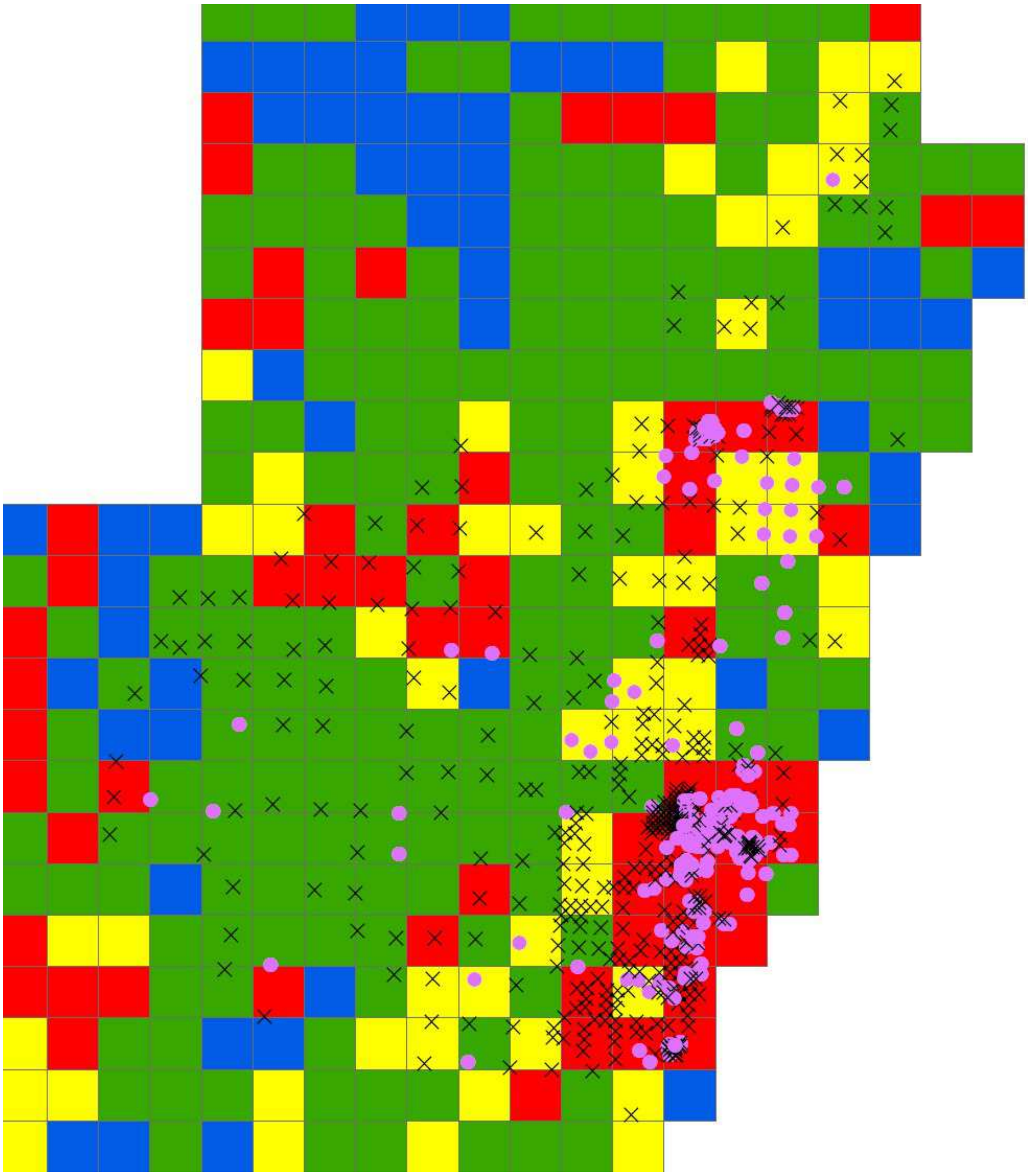

Figure 3. Distribution of Biolink SAT sites across same area referred to Figure 2 above. Active sites are indicated by closed pink circles, inactive sites by crosses. KLM baseline confidence categories for underlying 5 km cells are as follows: Red = ‘A’, yellow = ‘B’, green = ‘C’ and blue = ‘no data’.

Progressive incorporation of Atlas records and SAT data via the BCS affected changes in the confidence levels of 4 of the 503 10 km x 10 km cells and 29 of the 2065 5 km x 5 km cells that constitute KMA 1. Collectively, these data resulted in increases in the numbers of 10 km ‘A’ class confidence cells of approximately 2%, while the numbers of ‘B’, ‘C’ class confidence cells and those with no data decreased commensurately. At the 5 km cell level of resolution, the same data resulted in a similar proportional increase in the numbers of ‘A’ class confidence cells of approximately 6 %, as well as smaller increases in the ‘B’ and ‘C’ class confidence cells. Table 1 provides a breakdown of the resulting changes.

Table 1. Resulting changes to baseline KLM confidence categories ‘A’, ‘B’, ‘C’ and ‘No Data’ at 5 km (KMA 1 only) and 10 km cell (all of NSW) levels of resolution that arise from updating (to January 2016) with SAT data and Wildlife Atlas records. Changes resulting from input of Atlas and SAT records are shown respectively, the associated figures in brackets (10 km cells) reflecting changes that specifically relate to KMA 1.

Confidence	Baseline	Atlas	SAT	Baseline Update (Atlas + SAT)	change
5 km Cells					
A	399	403	416	422	+23
B	254	256	259	259	+5
C	929	926	934	930	+1
No Data	483	480	456	454	-29
10 km cells					
A	746 (207)	750 (208)	na (211)	754 (211)	+8
B	393 (140)	394 (140)	na (138)	393 (139)	0
C	1759 (140)	1767 (140)	na (140)	1766 (139)	+7
No Data	5392 (16)	5379 (15)	na (14)	5377 (14)	-15

Development of a Rapid-SAT survey methodology

Data from 59,601 trees associated with 2,073 SAT sites distributed across 12 Local Government Areas from Port Stephens on the mid north coast of NSW to the City of Gold Coast LGA over the time period 1995 – 2015 were available. From these sites a qualifying data set of 12,470 trees from 702 active sites could be extracted for evaluation, from which two data sets collectively containing the species Swamp Mahogany, Forest Red Gum and

Tallowwood were isolated as having strike rates that were significantly higher than all other species in the informing data set (Table 2).

When all active SAT sites containing the aforementioned three species are removed from the informing data set, only 3 species remained that met the qualifying criteria, each of which was homogeneous for statistical purposes. Of these, Grey Gum has the highest strike rate commensurate with and statistically indistinguishable from that of Tallowwood. For field survey purposes these four species are hereafter referred to as *Designated Target Species* (DTS). Based on this knowledge, two rapid assessment survey methodologies driven by DTS and focused on koala presence/absence were developed. The rationale and protocols of the resulting survey methodology are detailed in Appendix 2, the associated data sheet in Appendix 3.

Table 2. Strike-rates for 14 qualifying species of Eucalyptus in KMA 1 ranked in terms of the probability (p) of one or more koala faecal pellets being present within 1 m from the tree base *sensu* Phillips and Callaghan (2011). Standard Errors have been calculated using the binomial term $\sqrt{pq/n}$. Proximity corrected data summary indicates strike-rate for qualifying species in absence of the three most commonly utilized species. n_t = number of trees in sample.

Tree Spp.	n_t	p (%)	q (%)	SE (%)
E. robusta	2725	**43.3**	56.9	0.01
E. tereticornis	472	**41.9**	58.2	0.02
E. microcorys	2262	**37.8**	62.2	0.01
E. propinqua	787	26.4	73.6	0.02
E.racemosa	875	25.3	74.7	0.01
E. grandis	501	23.8	76.2	0.02
E. resinifera	391	23.8	76.2	0.02
E. saligna	139	22.3	77.7	0.04
E. acmenoides	322	17.7	82.3	0.02
E. globoidea	404	17.6	82.4	0.02
E. siderophloia	935	15.6	84.4	0.01
E. pilularis	2168	16.6	83.4	0.01
E. carnea	369	9.2	90.8	0.02
E. seeana	120	10.0	99.0	0.03
Proximity corrected				
E. propinqua	253	**40.7**	59.3	0.03
E. carnea	219	32.9	67.1	0.03
E. siderophloia	245	23.3	76.7	0.03

Field Survey

The field survey program provided data from 268 primary field sites and 110 ancillary data points (*i.e*. additional DTS sampled within 500 m of a primary site) distributed across 27 of the 10 x 10 km cells and 79 of the associated 5 km x 5 km cells between Dungog in the south, the Tweed Valley in the north and localities such as Nowendoc and Dorrigo in the west towards the escarpment. Not all of the 10 km cells and their constituent 5 km cells that were identified for survey could be accessed because of tenure considerations and/or a lack of secondary roads and/or trails.

Koala faecal pellets were detected in 75 of the 268 primary field sites with ancillary data responsible for changing the koala activity classification of a primary field site from inactive to active in 3.7% (10/268) of sampled sites. Estimated occupancy rates in cells that contained koala activity ranged between 17% and 100%, while confidence measures in conclusions that cells were not likely to be supporting koalas at the time of survey ranged between 9% and 85% based on the minimum survey requirement assessment matrix contained in Appendix 2.

One or more DTS occurred in all but 3 of the 10 km x 10 km cells and 7 of the associated 5 km x 5 km cells sampled therein. The collective of 10 km and associated 5 km cells in which the DTS did not occur were all located in upland areas wherein vegetation communities were more typical of those expected in adjoining KMA 2 - Northern Tablelands. A single B confidence 10 km x 10 km cell was also sampled during the training phase of the field survey. Data from these three 10 km x 10 km cells as well as other B confidence cells (*n* = 6 x 5 km x 5 km cells) are excluded from the analyses that follow but were otherwise uploaded through the KLM BCS.

Tallowwood and Forest Red Gum were the most commonly encountered DTS, collectively being represented in 83% of the 269 primary field sites. The mean numbers of DTS sampled at each primary field site approximated 6 (Mean = 5.94 ± 0.22 (SE) DTS site^{-1}, range 1 – 20). There was no significant difference between the mean number of DTS live stems in areas where koala faecal pellets were detected, and those where they were not (Levene's Test: $F = 1.06$, 173_{df}, $P = 0.41$; $t = -0.606$, 227_{df}, $P = 0.545$).

In terms of the KLM, the preceding results can be further partitioned as follows:

a) 5 km cells

Seventy three cells collectively representing the three cell categories "No data", "C (sub-set no koala)" and "A (probability range sub-set)" were sampled. Evidence of koalas was recorded in all categories. A breakdown of the occupancy outcomes for each of the three confidence levels that were sampled are as follows:

"No Data"

Koala activity was recorded in 11 of the 34 '*No data*' cells that were sampled, the associated occupancy estimates (active cells only) averaging approximately 60% of available habitat (mean proportion of active sites cell^{-1} = 0.62 ± 0.3 (SD).

"*C (no koala)*"

Koala activity was recorded in 4 of the 19 'C (no koala)' cells that were sampled, with occupancy estimates (active cells only) averaging 60% of available habitat (mean proportion of active sites cell^{-1} = 0.6 ± 0.27 (SD).

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"A (probability range sub-set)"

Koala activity was recorded in 15 of the 20 'A' cells that were sampled across the probability range 0 – 0.97, the associated occupancy estimates (active cells only) averaging approximately 60% of available habitat (mean proportion of active sites cell^{-1} = 0.59 ± 0.31(SD). Table 3 lists KLM probability estimates against the occupancy rate estimated by field survey. These data returned positive correlation values which were significant when assessed using a Spearman Rank approach ($r = 0.5432$, $P = 0.013$) and almost so using a Pearson product-moment approach ($r = 0.4422$, $P = 0.0509$).

Table 3. Comparative breakdown of differences between KLM probability estimate *p* and koala occupancy estimate (k_o) for a series of 20 x 5 km x 5 km randomly selected 'A' confidence category cells in KMA 1. *n* = numbers of field sites informing occupancy estimate.

Cell ID	p_{klm}	k_o	*n*
328	0.09	0.5	6
375	0.06	1	1
376	0.08	1	4
527	0.53	0.5	4
576	0.52	0.25	4
811	0.71	0.25	4
812	0.83	1	6
859	0.97	1	4
861	0.57	0.33	3
1671	0	0	5
1719	0.02	0	6
1815	0	0	2
2141	0.27	0.33	3
2142	0.46	0.4	5
2143	0.17	0.25	4
2144	0.41	0	1
2189	0.59	1	1
2190	0.89	0.6	5
2191	0.47	0.5	4
3624	0	0	9

Incorporation of Rapid-SAT field survey results resulted in increases in the numbers of 5 km ‘A’ and ‘C’ cells, while the numbers of 5 km ‘B’ and ‘No Data’ class confidence cells decrease. Table 4 provides a breakdown of the resulting changes. At the 10 km cell level of resolution, there was a decrease in the numbers of ‘no data’ cells and a corresponding increase in the numbers of ‘B’ and ‘C’ cells; no increase in the numbers of ‘A’ cells was effected.

Table 4. Resulting changes to updated baseline (Table 1 refers) KLM confidence categories ‘A’, ‘B’, ‘C’ and ‘No Data’ for 5 km (KMA 1 only) & 10 km cells (all of NSW) that arise from updating with Rapid-SAT field survey results. nc = no change.

Confidence	Updated Baseline	Baseline Update ('Rapid-SAT’)	change
5 km cells			
A	422	424	+2
B	259	258	-1
C	930	961	+31
No Data	454	422	-32
10 km cells			
A	750	750	nc
B	392	393	+1
C	1758	1762	+4
No data	5390	5385	-5

b) 10 km cells

A breakdown of the occupancy outcomes obtained for each of the three confidence levels that were sampled is a follows:

“No Data”

Koala activity was recorded in 4 of the 7 ‘No data’ cells that were sampled, with cell-based occupancy estimates (active cells only) averaging 40% of available habitat (mean proportion of active sites cell^{-1} = 0.395 ± 0.32 (SD).

“C (no koala)”

Koala activity was recorded in 4 of the 7 ‘C (no koala)’ cells that were sampled, with occupancy estimates (active cells only) averaging approximately 42% of available habitat (mean proportion of active sites cell^{-1} = 0.415 ± 0.08 (SD).

"A (probability range sub-set)"

Koala activity was recorded in 6 of the 10 randomly selected 'A' cells that were sampled, with cell-based occupancy estimates (active cells only) averaging approximately 44% of available habitat (mean proportion of active sites cell^{-1} = 0.44 ± 0.27 (SD).

Table 4 lists KLM probability estimates against the occupancy rate estimated by field survey. These data were positively associated, and there was significant correlation between KLM probability estimates and the habitat occupancy rate estimated by field survey when assessed using a Spearman Rank approach (r = 0.7268, P = 0.017), but not when using a Pearson product-moment (r = 0.4821, P = 0.1582).

Table 4. Comparative breakdown of differences between KLM probability estimate p and koala occupancy estimate (k_o) for a series of 10 x 10 km x 10 km 'A' confidence category cells in KMA 1. n = numbers of field sites informing occupancy estimate.

Cell ID	p_{klm}	k_o	n
8296	0	0	15
9168	0.04	0	24
10159	0.4	0.36	14
10160	0.31	0.33	9
10660	0.02	0	12
10784	0.008	0	14
11902	0.8	0.81	16
11903	0.73	0.08	13
12276	0.53	0.36	11
12520	0.04	0.7	10

A summary of the data resulting from the field survey program is provided in Appendix 3 (to be supplied as Excel spreadsheet).

4. Discussion

Occupancy studies are increasingly at the forefront of ecological endeavor. For koalas, accurately predicting occupancy is not simply about the presence of resources such as preferred food trees. In addition to the habitat consideration, relevant historical disturbances relating to land clearing, fire and logging, as well as habitat fragmentation for agriculture and urban development purposes as well as the location of such things as linear infrastructure must also be incorporated. Unfortunately, the information necessary to make informed decisions regarding the occupancy status of given areas of indicative koala habitat is rarely forthcoming. This project has examined several aspects of the Koala Likelihood Map developed by Predavec *et al.* (2014), the over-arching intent of which is to help inform natural resource management decisions that include the management of forestry activities on private land.

The KLM is primarily informed by calculations based on consideration of arboreal mammal records over the preceding twenty year interval and thus reflects averaged trends in koala distribution and abundance over that time period more than it does a contemporaneous (current koala generation) perspective. The recent listing of koala populations on the Tweed & Brunswick coasts as endangered population highlights the difference between these two considerations whereby generational persistence analysis over similar time frame utilized for the KLM implied a population at optimal occupancy rates, whereas a contemporaneous field based assessment indicated that a 50% reduction in occupancy rate had occurred within the previous 5 – 6 year period (NSWSC 2015, Phillips *et al* 2010[3]). In a conservation context it is reassuring that for KMA 1 at least a relatively large number of koala records have been forthcoming in the intervening period since the KLM was first produced, that rapid field assessment can independently reaffirm population persistence in areas where the species was already considered highly likely to occur on the basis of available knowledge and also that the same field assessment process can quickly establish the presence of previously

[3] Appendix 1 refers

unreported koala populations in areas where there were previously no records at all. Such results – in part at least – indicate that the KLM's lower confidence levels better reflect the absence of recorders and/or appropriately targeted survey effort than they do the potential absence of koalas.

A primary objective of the KLM project should be to progressively increase the numbers of 'A' confidence class cells at both 10 km and 5 km levels of resolution. To this end indications of a positive relationship between field-based occupancy estimates obtained by this study and the associated KLM probability estimate for the subset of sampled 'A' class cells is useful because it appears to offer independent corroboration of the KLM approach that – for cells in the A class confidence category - the associated probability of occurrence estimate appears to be a reliable indicator of the likelihood of occurrence. While there remains a chance that both approaches are incorrect, development of a method that enables rapid field assessments to be undertaken clearly offers an alternative approach by which the KLM can be further advanced independently of the need for physical sightings of koalas and other arboreal mammals. The presence of a potentially compatible and demonstrably more resource efficient survey method (in terms of the results and area able to be covered) further implies that the progressive upgrading of all 'No data', 'C' and 'B' class confidence categories to that of 'A' can be realistically achieved.

The numerical cut-off values employed by the KLM project to apportion cell-based confidence levels and those promulgated by the Rapid-SAT approach to define 'absence' arise from different intellectual processes. Despite the differences in approach the two techniques appear similar in terms of the underlying effort considered to best inform the respective outcomes. Because they come from different ends of the abundance/detectability spectrum however, the extent of any relationship is likely to be coincidental and so remains to be further investigated. The underlying consideration in both approaches however, goes to the question of what should qualify as the minimum area/cell-based survey effort. Given that the proportion of koala records relative to those of other arboreal mammal approach utilized by the

KLM is positively and significantly correlated with Rapid-SAT occupancy estimates we consider that minimum survey effort parameters required to determine absence might also be of associative utility in terms of indirectly supporting the required minimum survey effort for the former.

While the approach to determining the specific numerical cut-off values utilized by the KLM is primarily driven by the numbers of records in a given cell, in designing the Rapid-SAT we considered the need to (ideally) be able apply a measure of statistical confidence to any determination of koala ‘absence’ from within a given survey area to be the more desirable outcome than simply establishing ‘presence’ *per se*. In order to achieve this and to also avoid potential considerations of spatial auto-correlation, for each 5 km (2,500 ha) cell we utilized the maximum sampling interval of 1 primary field site at 1 km intervals, while also determining minimum DTS sample sizes, consideration of both parameters being required in order to enable a measure of statistical confidence in any conclusion that koalas were unlikely to be present. In contrast, in areas/cells where presence of the species was confirmed by field survey, the actual numbers of trees and associated contributing field sites is arguably becomes of lesser concern, but ideally the numbers of field sites should be optimized so as to enable, if so required, some understanding of the uncertainty around the resulting occupancy estimate.

The Rapid-SAT methodology developed for the purposes of this report appears to offer a useful technique enabling resource-effective assessments of forest/woodland areas that contain DTS. Interestingly, the broad result of 75/268 (28%) active sites is in accord with the average estimates of occupancy by koalas across NSW that can be deduced from other studies (e.g. Martin & Phillips 2013; Phillips 2013; Phillips & Allen 2012). However, the ability of the technique to resolve matters of presence/absence/occupancy remains contingent upon accurate identification of preferred koala food tree species at KMA scale and their assignation as DTS for survey purposes.

In areas where koala activity was recorded, ancillary DTS data was responsible for changing the status of a given primary site from inactive to active in less than 4% of sites. This implies that in areas being utilized by resident koala populations evidence should be readily detectable at 1 km intervals in greater than 95% of instances. Hence, the numbers of ancillary sites become of little mathematical consequence in areas where koalas are known to occur, but clearly have the potential to increase certainty in areas where absence of the species is becoming increasingly likely with ongoing survey effort (herein measured as a low probability estimate for KLM purposes). Given these considerations, decisions relating to the application and intensity of Rapid-SAT can be further refined to enable ongoing assessments to proceed independently and in a more resource effective manner. There are a number of avenues that may enable some prioritisation of this task to occur, including cell confidence levels, presence of tall forest cover, logging proposals, secondary track network and tenure.

The ease with which koala faecal pellets were detected in areas being utilized by koalas across the range of confidence categories that were sampled tends to confirm the notion that KLM confidence categories are initially influenced by observer density and can thus be independently and confidently upgraded by further survey effort across all categories. Given the low numbers of survey sites that were actually able to be completed for each accessible 5 km cell (despite our intentions to the contrary), further consideration could be given to soliciting access to other areas of forest and/or reducing the spatial consideration from 1 km to 500 m.

Recommendations

Adjusting KMA boundaries.

In some western upland areas of KMA 1 the field survey program was thwarted and/or resorted to assumption when DTS were absent and the tree species encountered were more typically aligned with KMA 2 – Northern Tablelands vegetation communities. This circumstance implies the need for DTS for adjoining KMAs to be identified/resolved ahead of future survey program so that such areas can also sampled more effectively.

Presence of koala populations in 'No data' and 'C (No koala)' cells.

Field survey readily detected the presence of resident koala populations in approximately 30% of cells so designated. Such results confirm the importance and need for ongoing survey in these confidence classes to progressively update knowledge regarding the likelihood of koalas in such areas.

Testing & further refinement of confidence level thresholds.

There is a broad spread of central tendency measures around the survey effort measure utilised by the KLM for the 'A' confidence levels. Given this consideration, it is likely that the C_{max} threshold which currently distinguishes 'A' class confidence cells could be further partitioned, the end result of which would be creation of a minimum of 4 KLM confidence categories rather than the current 3. Regardless, there are some grounds for also investigating the potential for lowering the current 'A' class confidence threshold to effectively capture some the current 'B' class cells. This could be done experimentally through a progressive lowering of threshold values and testing through iterative correlation/regression.

Minimum Survey Effort.

In considering the numbers of survey units detailed in Table 2 of the work by Predavec *et al* (2014), we propose that a measure of 100 (absence) – 110 (presence) survey effort units at 10 km scale of resolution best reflects the confluence of minimum survey effort required to achieve 'A' confidence level classification from both ends of the abundance spectrum. In contrast to the KLM approach however, we further consider that this requirement should also be scalable as detailed in Appendix 2 depending on the amount of koala habitat present assessed to be present within the associated grid cell.

Spatial auto-correlation.

Given that typical arboreal mammal survey programs simply record koalas and other sighted mammals regardless of spatial auto-correlation considerations and that home range overlap is a feature of koala population structure, we consider that a 500 m interval between sampling points should be considered appropriate for the purposes of further Rapid-SAT surveys undertaken for the purposes of informing the KLM.

Limiting Application of the KLM.

Given that probabilities of koala likelihood/occurrence remain to be resolved for KLM confidence classes below that of ‘A’ it is necessary to restrict development of such things as management prescriptions to guide forestry practices on private land to ‘A’ confidence levels only.

Prioritising areas for upgrading.

Given that the current extent of private native forestry operations are considerable and will only increase in the face of a diminishing crown forestry resource, it makes sense for an initial focus to be on the upgrading of confidence categories of all 10 km and 5 km cells below ‘A’ that are located in areas where PNF activities are widespread and/or pending.

SAT Data – Bionet/Atlas Interface

There are currently no provisions for null data (i.e. SAT sites that did not record koala activity) to be entered into the Wildlife Atlas. Given that such data has utility in terms of informing KLM confidence classes and associated probability of koala likelihood estimates, development of an appropriate interface enabling such data to be entered and/or accessed for KLM purposes would appear warranted.

Acknowledgements

Our thanks are extended to EPA officers Bill Faulkner and Dr. Chris McLean, and to Dr. Martin Predavec (OEH) for their assistance with this project, including overall project management (BF), fieldwork (BF and CM) and the provision of guidance and constructive criticism (all) over the course of the project and various iterations of the draft report. The problem was the human hand holding the koala scats so we resolved – how (disturbingly) Orwellian. For contributions at our end we also thank John Callaghan, Paul O’Callaghan and Jim Dick for feedback throughout the process of development, trialing and

implementation of the Rapid-SAT methodology and thereafter the formal field survey program.

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Appendix 1

Details of SAT survey data contributing to update of KLM baseline model and development of Rapid-SAT method (Note: all studies undertaken by Biolink unless otherwise indicated).

Appendix 1

LGA	*n*	Date	Study
1. Complete Data sets			
Byron	33	2007	*Yelgun Koala Survey (SEPP 44 Assessment) & KPoM*
	30	2010	*Koala Habitat Assessment and Monitoring Program (Bluesfest)*
	14	2010	*SEPP 44 Koala Habitat Assessment, Ewingsdale Road, West Byron (including Belongil Fields)*
	63	2012	*Byron Coast Koala Habitat Study*
Ballina	75	2013	*Koala Habitat & Population Assessment: Ballina Shire Council LGA*
Coffs Harbour	81	2015	*Aspects of koala distribution and abundance in the Coffs Harbour LGA with a focus on the northern management precinct.*
Gold Coast	315	2007	*Koala Habitat & Population Assessment for Gold Coast City LGA*
Great Lakes	68	2005	*North Hawks Nest KPoM*
Kempsey	110	2009	*Comprehensive KPoM for Eastern Portion of Kempsey Shire LGA (Vol II - Resource Document)*
Port Macquarie – Hastings	405	2013	*Port Macquarie Hastings Koala Habitat & Population Assessment*
Richmond Valley	58	2015	*Koala Habitat & Population Assessment: Richmond Valley Council LGA.*
Tweed	87	2005	*Kings Forest Koala Plan of Management*
	134	2011	*Tweed Coast Koala Habitat Study*
2. SAT Data Summaries			
Port Macquarie Hastings	29	1995	*An Assessment of Koalas and their Habitat on the Dunbogan Peninsula – Management Associated with the Proposed Camden Shores Residential Canal Estate* (Data Source: Australian Koala Foundation).
Richmond Valley	128	2008	*Richmond Valley Koala Habitat Atlas* (Data Source: Australian Koala Foundation)
Tweed	70	1996	*Tweed Koala Habitat Atlas* (Data Source: Australian Koala Foundation)
Port Stephens	58	1994	Phillips *et al.* (2000). The tree species preferences of koalas (*Phascolarctos cinereus*) inhabiting forest and woodland communities on Quaternary deposits in the Port Stephens area, New South Wales. *Wildlife Research* **27**, 1 - 10.

Appendix 2

Development of a SAT-informed Rapid Koala Habitat Assessment Methodology.

(Rapid-SAT)

Appendix 2

Preamble

The preceding report isolated a suite of four species – Swamp Mahogany, Forest Red Gum, Tallowwood and Grey Gum as being the tree species most widely distributed and consistently preferred by koalas across KMA 1. These species were subsequently categorized as Designated Target Species (DTS). To this list could potentially be added other less widely distributed species such as Parramatta Red Gum, Grey Box and Red Mahogany that are known on the basis of localized studies to also be the subject of preferential utilization.

Commensurate with the widespread distribution of Tallowwood and Grey Gum, the greater proportion of habitat within KMA 1 occurs on erosional soils landscapes and/or uplifted meta-sediments. SAT data from these landscapes confirms that size-class based model of tree selection by koalas such that trees in the larger size-classes of 250 mm – 300 mm and above can be more reliably associated with the probability of pellets than are the smaller size-classes (Figure A2.1).

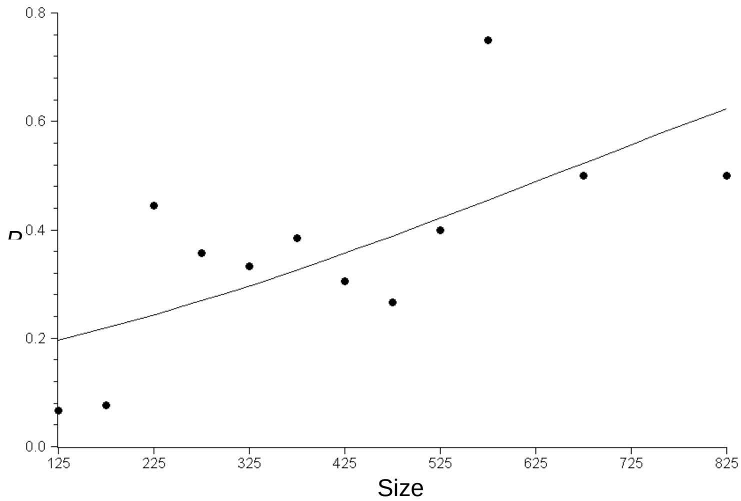

Figure A2.1 – Simplified logit model illustrating relationship between diameter at breast height (size) and strike-rate (*p*) for the preferred koala food tree Tallowwood (*Eucalyptus microcorys*) when growing on low-nutrient soils (Source: Phillips and Hopkins (2008) – East Kempsey CKPoM Resource Document).

For the purposes of Rapid-SAT we consider the probability of failure (*q*) to be the primary driver, specifically and somewhat counter-intuitively perhaps, the absence of one or more koala faecal pellets from beneath DTS that are otherwise known to have the greatest probability confirming presence thus functioning to best inform considerations of absence.

In terms of standard SAT/RG-bSAT protocols, a strike rate of approximately 0.5 or 50% within KMA 1 can be demonstrated to reflect 100% utilization of the associated resource by koalas. The survey methodology that follows is consequently designed around a probability of failure of 0.50 with sampling across a given area utilising a confidence interval length of 0.1 to accommodate a conclusion that koalas are absent from a given area. Figure A2.2 illustrates the relationship between statistical confidence and the DTS sample size in terms of the numbers of trees assessed, while Table A2.2. details the corresponding numbers of sites required to be sampled based on considerations/knowledge of the amount of koala habitat present within the area being surveyed.

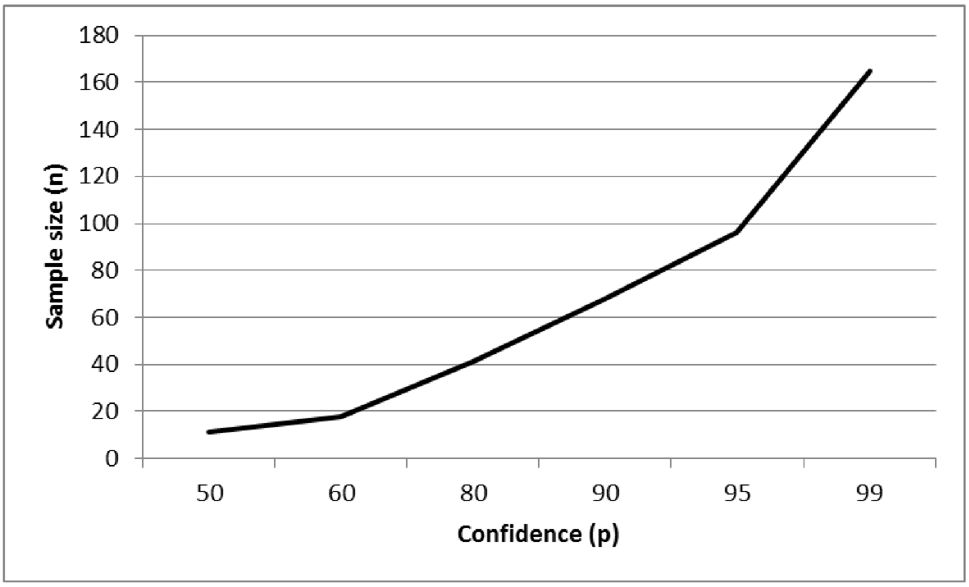

Figure A2.2. Confidence curve based on a 50% (i.e. 0.5) probability of failure and a confidence interval length of ± 0.1. The numbers of DTS sampled (Sample size) is presumed to have been obtained from the minimum numbers of independent field sites as specified in Table A2.1.

Table A2.1. Relationship between extents of koala habitat, numbers of Rapid-SAT surveys and numbers of DTS without pellets that must be sampled in a given 2500 ha cell in order to give effect to a conclusion that koala are not present. The numbers 50 – 99 indicate the corresponding measure of statistical confidence that applies.

% Koala Habitat	No. Sites/Confidence:	50	60	80	90	95	99
100	25	-	-	41	68	96	165
75	18	-	-	31	51	72	124
50	12	-	-	21	34	48	83
25	6	-	-	10	17	24	41
12.5	3	-	5	5	8	12	20

There are a number of ways by which the information presented in Table A2.1 can be utilised. Given that the measure '% koala habitat' may not always be known precisely, broader categories such as 0 – 25%, 25 – 50%, 50 – 75% and 75 – 100% may be designated, the informing of which (in terms of absence) should always be set at the upper % requirement such that 0 – 25% requires a minimum of 6 sites and 24 DTS to be sampled and so on. In areas where the requirements either cannot or haven't been met, the number of sites sampled should be the primary consideration (as opposed to the numbers of DTS) with adjustments made to accommodate the associated uncertainty. For example if '% koala habitat' is estimated at 50 but only 8 sites have been sampled for a total of 34 DTS, then the corresponding level of confidence in any conclusion that koalas are absent can be estimated as 8/12 (0.667) x 90% = 60%.

Objectives

The primary objectives of the Rapid-SAT approach is to be able to quickly establish koala presence within a prescribed survey area or alternatively, to conclude koala absence within the same area with a measure of statistical confidence (ideally 90% or better). A secondary objective in the event that koalas are present is additionally providing the capacity to quickly identify the area or areas within which resident aggregations/populations of the species occurs by way of one or more appropriately buffered[4] Minimum Convex Polygons (MCP) within which more detailed koala habitat and/or population

[4] Presuming a regularized, grid-based approach to assessment, this measure is determined to be 50% of the sampling interval.

assessments can be undertaken if required. The preceding objectives require different approaches in terms of how the methodology is applied.

Option 1

For surveys investigating koala presence/absence only.

1a. overlay the area of interest with a regularized grid of potential sampling points, the intervals between which should be generally in accord with the following table:

Size of area being assessed (ha)	Minimum Assessable Unit (ha)	Maximum sampling interval (m)
< 100	50	250
> 100 but < 500	250	350 - 500
> 500 but < 2000	1000	500 - 750
> 2000	2500	1000

or

1b. Locate as many sampling points as possible at regularly spaced intervals commensurate with those recommended in the preceding table (or approximations thereof) along secondary tracks and roads located within designated road reserves that traverse areas of Eucalyptus forest or woodland.

2. depending on the location of habitat patches and/or forested road reserves that are available for assessment and the distribution of the final site array resulting from 1a or 1b above, randomly select or otherwise plan to sample the required numbers of sampling points and DTS for the estimated amount of koala habitat as outlined in Table A2.1 and that above.

3. In the event that a given point cannot be sampled for whatever reasons (including the absence of DTS), a replacement sampling point should ideally be selected from any surplus sites or localities that remain within the MAU that is being assessed.

4. Upon determination of sampling point coordinates, a supporting vegetation assessment (*sensu lato* Phillips *et al*. 2013) should be completed within a 15 m radius and the bases of all DTS within this same area searched for koala faecal pellets using the sampling technique of Phillips & Callaghan (2011). Where a radial assessment is constrained by access considerations a linear assessment up to a maximum of 25 m either side of the selected sampling point is acceptable as an alternative.

5. The assessment at a given sampling point ceases when one or more koala faecal pellets have been detected or if no pellets are detected, all DTS have been assessed in accord with the sampling objectives and associated constraints identified by 2 - 4 above.

6. Individual and/or small groups of DTS opportunistically encountered between primary sampling points can also be assessed if required, the result being allocated to the closest pre-determined primary sampling point (but not replacing it).

Option 2

For surveys requiring an indicative *Extent of Occurrence* to be identified.

Note: this approach should be used when the presence of koalas is known or otherwise suspected, access is unrestricted and knowledge regarding the location and extent of the area being occupied by resident populations is required.

1. If required, stratify the sampling unit by vegetation formation/code/type.

2. Overlay the area of interest with a series of regularly spaced sampling points as detailed in the following table. Points that occur in vegetation formation/code/types that contain eucalypts will denote potential sampling points for the purposes of the assessment.

Size of area being assessed (ha)	Minimum Assessable Unit (ha)	Maximum sampling interval (m)
< 100	50	250
> 100 but < 500	250	350 - 500
> 500 but < 2000	1000	500 - 750
> 2000	2500	1000

3. Upload or enter site coordinates for each of the potential sampling points into a hand-held GPS to assist location in the field.

4. Locate yourself close to a designated site and commence navigation on foot to the site coordinates. Foot-based traverses between primary sampling points should also form the basis of broad (± 15 m either side) transect searches wherein all DTS are inspected for faecal pellets (*sensu* Phillips & Callaghan 2011); the result (i.e. presence/absence of koala faecal pellets), GPS coordinates and species name of such trees should be recorded to enable re-location if required.

5. Upon arrival at site coordinates, complete a rapid vegetation assessment within a 15 m radius of the site coordinates and inspect the base of all DTS within this same area for the presence of faecal pellets using the search technique described by Phillips & Callaghan (2011).

6. The assessment at a given sampling point ceases when one or more koala faecal pellets has been detected or all DTS within the constraints identified by 4 above have been sampled.

7. When the field survey is complete, a minimum convex polygon can be created by join the outermost points at which koala activity was recorded, in addition to the required buffer, the width of which should be 50% of the distance between sampling points.

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