SAVING OUR SPECIES

Framework for the spatial prioritisation of koala conservation actions in NSW

Iconic Koala Project

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Environment, Energy and Science
Department of Planning, Industry and Environment
59 Goulburn Street, Sydney NSW 2000
PO Box A290, Sydney South NSW 1232
Phone: +61 2 9995 5000 (switchboard)
Phone: 1300 361 967 (Environment, Energy and Science enquiries)
TTY users: phone 133 677, then ask for 1300 361 967
Speak and listen users: phone 1300 555 727, then ask for 1300 361 967
Email: info@environment.nsw.gov.au
Website: www.environment.nsw.gov.au

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Introduction

Background

Saving our Species (SoS) is a statewide program of the NSW Government that aims to secure threatened plants and animals in the wild in New South Wales. Under SoS, the koala (*Phascolarctos cinereus*) has been identified as one of six iconic NSW species that are important socially, culturally and economically, and which the community expects to be effectively managed and protected.

The Saving our Species Iconic Koala Project aims to secure the koala in the wild in New South Wales for 100 years by:

- reducing critical threats to the species
- ensuring adequate protection, management and restoration of koala habitat
- maintaining healthy breeding populations of koalas throughout their current range.

Between 2017 and 2021, the SoS Iconic Koala Project is coordinating koala conservation actions across New South Wales and providing seed funding for priority actions. Input from experts and the community is being combined with scientific analysis to identify those conservation actions likely to have the most significant outcomes.

Data-driven spatial analysis is needed to support koala conservation

The guiding document for the SoS Iconic Koala Project (OEH 2016a) clearly states the need for koala conservation actions to use data-driven spatial analysis to determine areas of significance, with priority investment for 2017–18 to include:

> Further spatial analysis, identifying areas of regional and local koala significance for future prioritisation of conservation actions.

Recommendations made in the Report of the Independent Review into the Decline of Koala Populations in Key Areas of NSW (NSW Chief Scientist & Engineer 2016) include:

- **Recommendation 1 –** That Government adopt a whole-of-government koala strategy for NSW with the objective of stabilising and then starting to increase koala numbers.

  The strategy should [among other things]:

  - identify key koala populations and management areas which have the potential for long-term recovery and viability
  - identify priority threats to key koala populations at the population scale, through mapping and establishing threat hierarchies.
- **Recommendation 7 –** That Government agencies identify priority areas of land across tenures to target for koala conservation management and threat mitigation.

In response to the above priority investment and recommendations of the Independent Review, a project has been funded under the SoS Iconic Koala Project with the aim of providing support and strategic direction to future priorities in conservation actions for the koala. It is one of many projects designed to support data-driven (evidence-based) decision-making for koala conservation.

Identifying areas of koala occupancy at risk of decline and important threatening processes

The impetus for the project has also stemmed from a growing body of evidence of declining koala populations in New South Wales. One of the most recent significant studies of east coast koala populations (Adams-Hosking et al. 2016) estimates koala populations in almost every bioregion in the State as being in significant decline. Table 1 shows many figures from the Adams-Hosking et al. study, including population estimates, trend status (declining, stable or increasing) and several records analyses. The overall trend of both the expert elicitation data (Adams-Hosking et al. 2016) and the records trend data (where available) points to an almost universal decline of koalas across New South Wales in recent years. The only bioregion with convincing evidence of a stable population from both expert elicitation and records trend data is the New England Tablelands.

While the bioregional analysis illustrated in Table 1 provides a useful overview of statewide trends, it has been observed by several studies (Scotts 2013, DECCW 2010a) that a more complex pattern of stable source koala populations and declining (sink) populations emerges within bioregions. The scale of the assessment conducted under this SoS-funded project has been designed to provide a statewide assessment of the areas of regional significance for koalas in New South Wales.

This project uses the concepts of **resilience** and **security** at a regional scale and **functional habitat** at an area scale to identify areas of koala occupancy which are at risk of decline. It provides an analysis of the landscape values important to koalas and threats to those values.

Drawing from these recommendations, the project includes three broad components, which are presented in separate reports:

- Audit of Statewide Spatial Datasets (Rennison 2017a)
- Assessment of the Current Reservation Systems and Protection of Koalas within the Bioregional Areas of NSW – includes a trial assessment of priority areas for acquisition in the South-East Highlands Bioregion (Rennison 2017b)
- Development of a Framework for the Spatial Prioritisation of Koala Conservation Actions in NSW (this report).

Relationship with other koala-related conservation programs

This project has been funded under the SoS Iconic Koala Project, however, there are several program streams within and outside of the Department of Planning, Industry and Environment which are operating concurrently and have similar objectives and/or data requirements. These are outlined below.

NSW Koala Strategy

The NSW Government is implementing a NSW Koala Strategy to stabilise and then start to increase koala numbers. The recommendations of the report that guided the establishment of the NSW Koala Strategy include the identification of land across tenures to target for conservation management and threat mitigation.

This project provides a set of tools which are suitable to assist in the strategic prioritisation of conservation management programs. The identification of key koala population areas at statewide and regional scales and the associated measures of security, functional habitat and resilience, provide a useful framework for more detailed analysis and actions at the local scale.

NSW National Parks and Wildlife Service acquisition program

One pillar of the NSW Koala Strategy is an initiative to assist in the long-term protection of priority koala habitat. The NSW Government has allocated $20 million over five years to purchase and conserve private land to protect priority koala habitat (OEH 2018b). These purchases are to be made in line with National Parks and Wildlife Service (NPWS) acquisition criteria, with a focus on koala habitat and occupancy.

This project provides a set of tools which are suitable for applying in a decision support framework to assess potential properties for addition to the reserve system.

Statewide koala information base

As part of the NSW Koala Strategy, the Department of Planning, Industry and Environment is developing a statewide koala habitat information base. The information base will use the best available data on koala distribution, koala preferred trees and koala sightings.

The key layers in the information base are a regionalised list of tree species used by koalas, a map of the likelihood a koala will occur, and predictive models of koala habitat suitability and koala tree suitability.

This project provides another one of the key layers included in the information base package.

Biodiversity Conservation Trust

The NSW Biodiversity Conservation Trust (BCT) works in partnership with landholders to establish private land conservation agreements to conserve and manage high value biodiversity on private land.

This project provides a set of tools that can contribute to the priority investment areas (e.g. core area mapping) identified by the BCT, including areas of identified high resilience, low security and high connectivity value.

Table 1 Koala populations across NSW IBRA regions

IBRA name	Population estimate (Adams-Hosking et al. 2016)	Status (stable, declining, sharply declining) from Adams-Hosking et al. 2016	Observations since 2011 (current generation)	Koala observations as a proportion of all arboreal observations (as a measure of survey effort)	Records analysis Stable or declining (since previous generation/s)	Overall trend
Brigalow Belt South and Nandewar	11,133	Declining (–35%)	292	11%	Overall decline over analysis period	Declining
Cobar Peneplain and Riverina	2,354	Declining – stable (–9%)	2	15%	Insufficient data	Declining – stable
Darling Riverine Plains	964	Declining (–34%)	2	25%	Insufficient data	Declining
Mulga Lands	711	Declining (–31%)	0	N/A	Insufficient data	Declining
Murray Darling Depression	55	Declining – stable (–12%)	0	N/A	Insufficient data	Declining – stable
New England Tablelands	2,771	Stable – increasing (+6%)	79	1%	Slight decline over analysis period	Stable
NSW North Coast	8,367	Declining (–50%)	2,010	21%	Overall decline over analysis period	Declining
NSW South Western Slopes	2,310	Declining (–23%)	3	0%	Overall decline over analysis period	Declining
South East Corner	655	Declining (–46%)	213	4%	Declining over last generation, but stable overall	Declining – stable
South Eastern Highlands	1,363	Declining (–19%)	323	5%	Overall decline over analysis period	Declining
South Eastern Queensland (QLD figures)	15,821	Declining (–51%)	1,801	51%	Increase over recorded period*	Declining

Sydney Basin	5,667	Declining – stable (–4%)	406	5%	Moderate decline over survey period	Declining – stable

* Increase in recorded occurrence of koalas in South East Queensland over past three generations associated with increased focus on koala management and accompanying survey effort including CKPoM SAT data and Dan Lunney's Community Wildlife Survey.

Establishing a framework for prioritising koala conservation actions

A central challenge of the SoS Iconic Koala Project is to ensure that threats to koala populations in New South Wales are effectively and efficiently managed and that management efforts are targeted at the most significant threats.

This project aims to prioritise conservation action and investment by targeting areas known to be occupied by significant koala populations (OEH 2016a). A spatial prioritisation framework has therefore been developed to help guide the implementation of the most cost-effective actions.

Six broad steps have been identified in the process for prioritisation of koala conservation actions in New South Wales. The process loosely follows a traditional risk assessment design, with threats considered in the context of their likelihood of occurrence and potential for consequences on the values considered important for securing koala areas into the future.

Step 1 identifies the main areas of New South Wales with significant populations of koalas, while Step 2 identifies key threats to those populations. Step 3 examines the values which are supporting the persistence of koalas in these areas and Step 4 looks at risks to their persistence. Future ‘resilience’ for koala areas is predicted in Step 5, based on the level of risk that the values are exposed to and, together with the resilience class, the threat risk classes are used in Step 6 to identify the most appropriate management strategies offered by the action toolbox[1] to mitigate the threats considered to be important for each koala population.

Figure 1 sets out the six steps followed in establishing the spatial prioritisation framework and Figure 2 represents this framework in terms of the conceptual flow of the data analysis and outputs tools for prioritisation of koala areas. The six steps are outlined in detail in the next chapter.

[1] Species in the landscape management stream of SoS each have an ‘action toolbox’ in the SoS database. A species’ toolbox defines specific, practical and meaningful actions for controlling critical threats and securing populations on the ground (OEH 2015b).

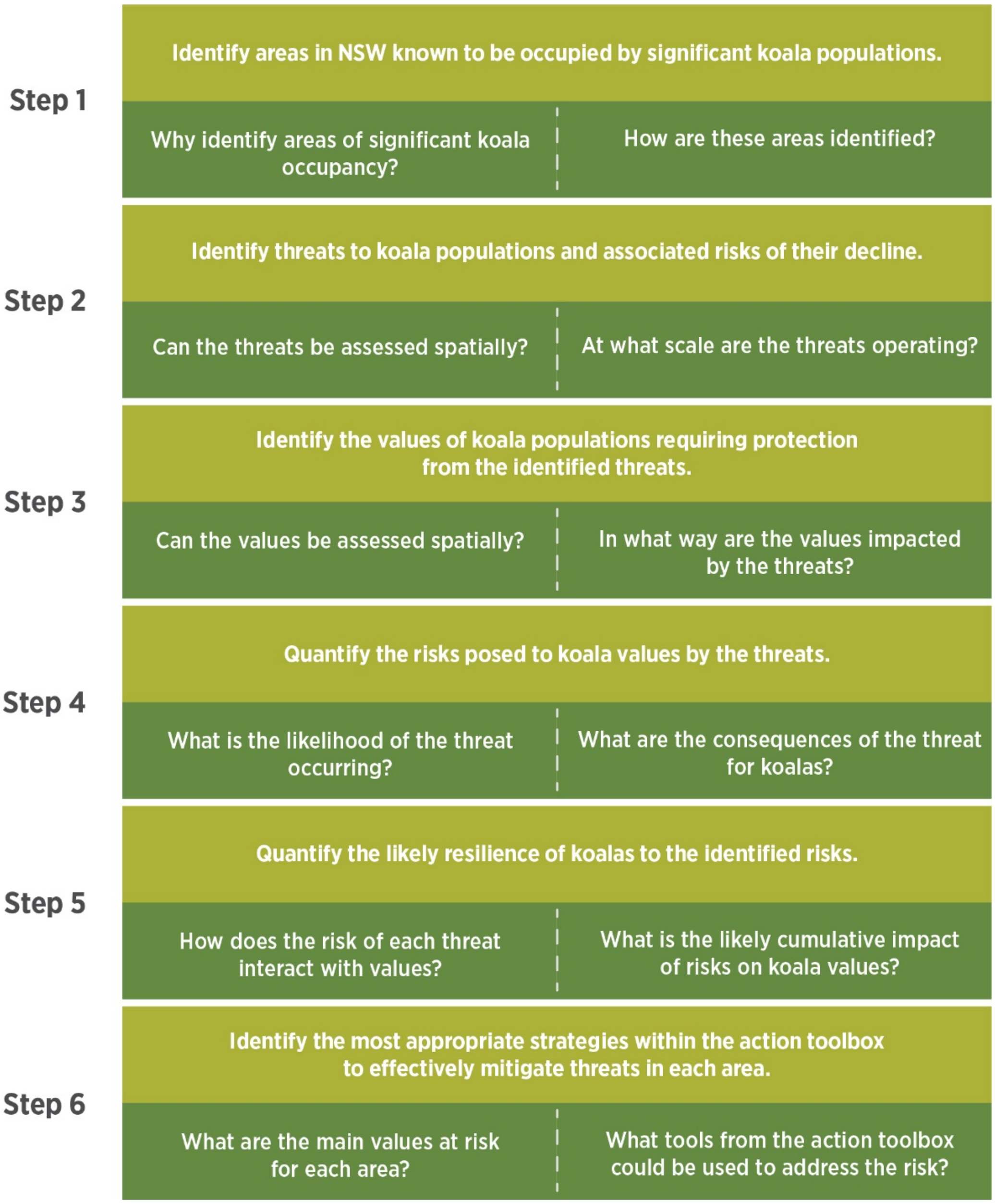


Figure 1 **Process steps for establishing the action prioritisation framework**

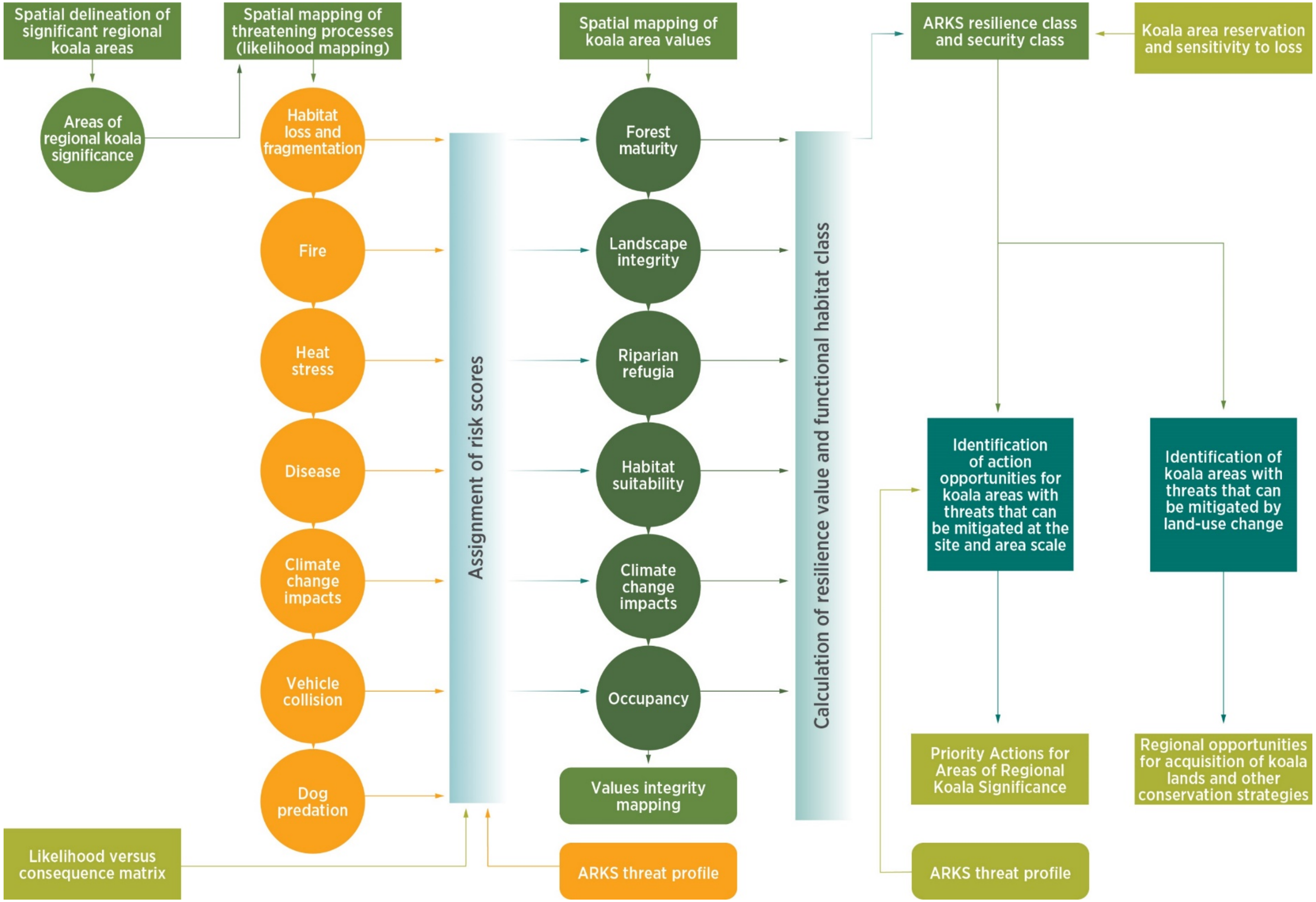


Figure 2 **Process diagram for identifying actions for Areas of Regional Koala Significance**

Step 1: Identify areas in NSW known to be occupied by significant koala populations

Rationale

As a basis for a NSW-wide prioritisation analysis, there is a requirement for a consistent, tenure-blind and current spatial assessment of areas which are known to have high regional significance for koalas.

The intent of these spatially defined areas is primarily to delineate focus areas for the analysis of resilience and security characteristics including habitat values and risks to the persistence of koalas in these areas. These focus areas will then be used for more detailed analysis of threats and values which in turn will drive priorities for koala management strategies, conservation action and funding.

These areas are not designed to be an exhaustive account of all koala occupancy across New South Wales, but rather define areas of currently known high koala occupancy, commonly regarded as koala regional populations or meta-populations (terminology is variable).

Dealing with uncertainty and bias in knowledge

Historically, only small areas of land in New South Wales have been systematically surveyed for koala activity. These habitat studies have usually been undertaken as part of pre-harvest surveys (Forests NSW), regional conservation assessments or a Comprehensive Koala Plan of Management. Since 1990, over 22,000 koala observations have been recorded in New South Wales.

The koala likelihood of occurrence map (OEH 2015a) uses survey effort to score the confidence with which the likelihood estimates are calculated. Most areas of New South Wales (including large parts of the north coast) have a low confidence, albeit presenting likelihood of koala occupancy. An example of the confidence of occurrence mapping is shown in Figure 3.

While the risk associated with the lack of a comprehensive unbiased dataset cannot be eliminated, the analysis of statewide, regional koala areas has been consciously structured to be inclusive in recognition that many areas of koala populations in New South Wales are poorly sampled and may also occur at low densities. In full recognition of data bias, it is worth noting that 92% (over 20,000) of filtered koala records occur within mapped significant koala areas. The identified areas have also been validated against available published (Scotts 2013, Paull & Hughes 2016) and OEH sources (DECCW 2010a). Where possible and appropriate, equivalencies to these published populations have been provided.

How these areas were identified

The Areas of Regional Koala Significance (ARKS) were identified using analysis of koala observation densities, followed by spatial filtering of non-habitat features, incorporating barrier information where available.

A total of 48 ARKS were identified, with the smallest being South West Rocks, at around 400 hectares, and the largest being Bungonia (Illawarra) at 353,000 hectares (made up of five sub-areas). Altogether, 4,195,549 hectares (~42,000 square kilometres), or around 5% of New South Wales is mapped as being of significance for koalas.

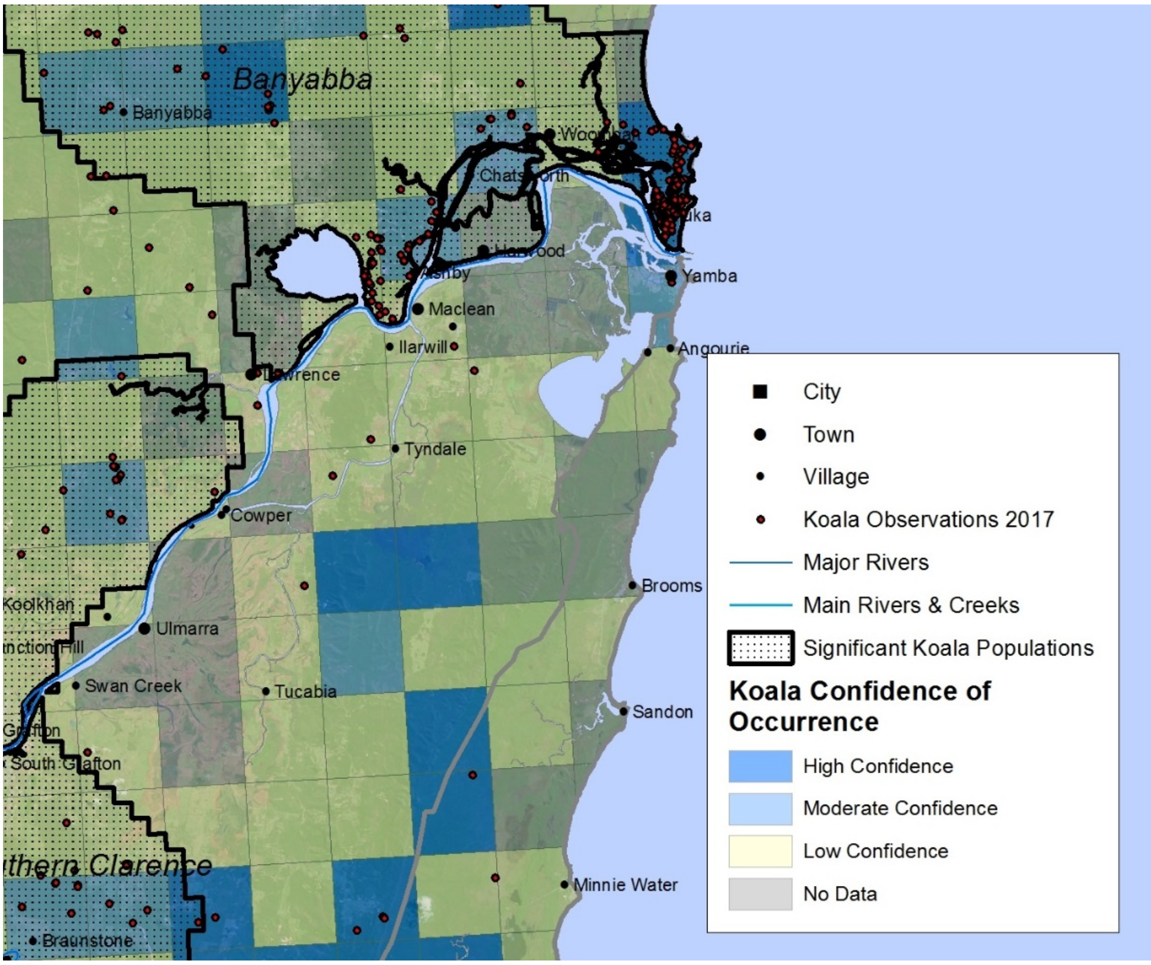


Figure 3 Confidence of likelihood of koala occupancy in Mid North Coast New South Wales (Predavec 2016)

Density analysis

A kernel density analysis (ArcGIS toolbox) was used to analyse a minimum threshold of observations of koala occurrence across the NSW landscape. As a basis for this metric, a baseline search threshold of 10 km was adopted, reflecting what is generally accepted as the maximum seasonal movement of koalas across the landscape. For example, koalas studied in south-east Queensland moved on average 3.5 km (and up to 10.6 km) in their first breeding season (Dique et al. 2003a). Absence data for koala observations is restricted to SAT (scat search) surveys, which are largely associated with Comprehensive Koala Plans of Management. Absence (nil activity) data has therefore not been included in the analysis.

A very low threshold was used to set the minimum occupancy density for inclusion as a candidate area of significance. This approach was used to alleviate concerns that low-density koala populations or populations with inadequate survey may be excluded. While the limitations of current data will inevitably lead to inadequacies in the definition of areas of regional significance, it is hoped that a more inclusive analysis can minimise the effects of data deficiency. The final density threshold for candidate areas was set at 0.06 records per hectare, roughly equating to one observation per home range for medium density koala populations. Figure 4 shows an example of the density mapping output and the final koala area boundary with filters applied.

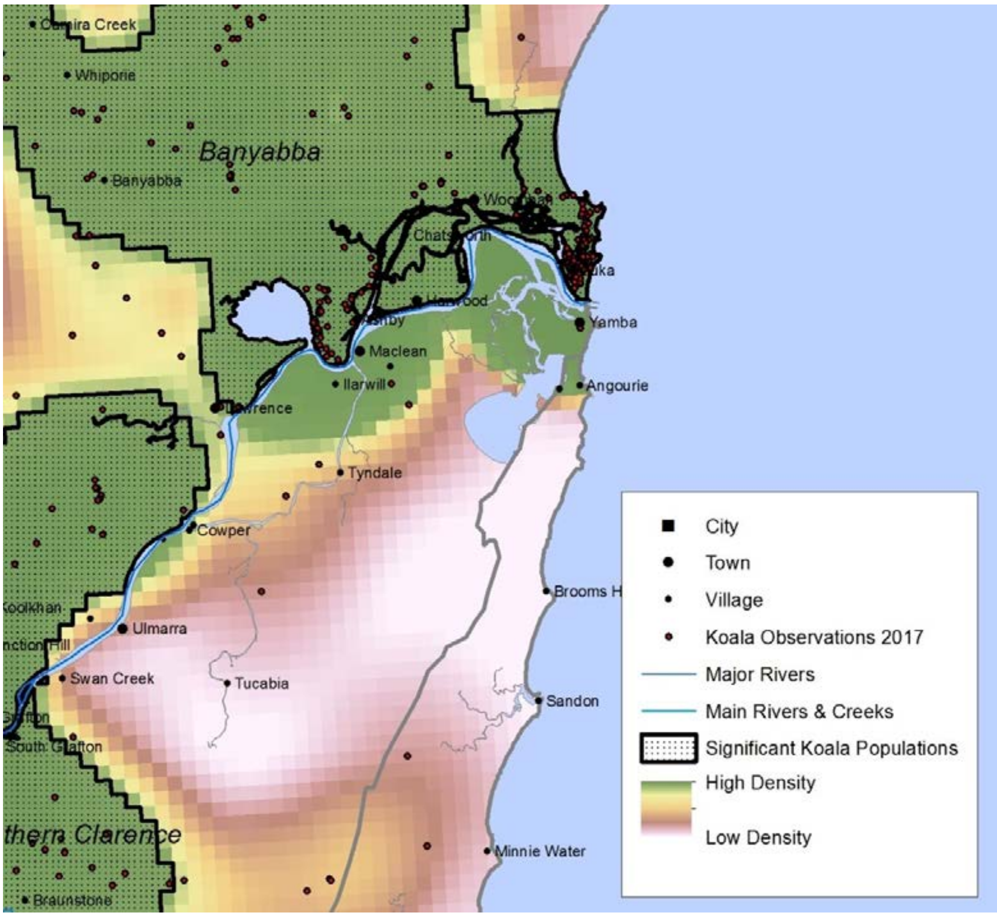


Figure 4 **Analysis of koala density in Mid North Coast New South Wales – Banyabba regionally significant area**

Application of filters

Several spatial and size criteria filters were applied to refine and consolidate regionally significant areas. These criteria have been designed to exclude likely non-habitat areas and consolidate likely habitat areas (where survey density is limited).

Minimum threshold for areas of significance

A minimum threshold for an area of 100 hectares was applied for areas of regional significance. This threshold was applied to exclude scattered and isolated koala occurrences, usually with limited evidence of continued (resident) populations.

Application of barriers to koala movement to split areas of regional significance

Known barriers to koala movement were applied and reviewed for effectiveness. Upper North Coast barriers (Millage 2016), Mid North Coast barriers (Scotts 2013) and Lower North Coast barriers (Kendall 2016) were initially applied and then reviewed for accuracy and comprehensiveness. Categories of barrier included:

- Pacific Highway sections (excluding sections where underpasses have been created to enable movement)
- riparian areas which form a barrier (major rivers with open water free of vegetation)
- rainforest areas
- altitudinal barriers (escarpment).

Exclusion of obvious non-habitat

Areas of obvious non-habitat were excluded where there was no evidence of recent koala occurrence and/or where the area was isolated by barriers such as those referred to above. Other isolated areas such as offshore islands or river islands with no recorded occurrence were also excluded.

Product specification and limitations

The ARKS have been mapped across New South Wales using an original grid analysis resolution of one kilometre. To apply the spatial filters and checks, the analysis result was converted to a polygon format and stored in a file geodatabase. A list of all ARKS is provided in Table 2 below and a map of their locations is presented in Figure 5.

The mapping has been designed to provide focus areas for the profiling and analysis of the landscape values and threats acting on koala populations in New South Wales. The analysis is being undertaken at a statewide scale and no attempt has been made to delineate fine-scale occupancy information. It follows that this dataset is not suitable for local scale/property assessments. As the areas were designed only to provide an envelope for analysis, no relative significance was assigned to areas. Finer-scale local plans and analyses can provide more detailed occupancy and habitat suitability information.

The basis for this analysis has been occupancy information. No attempt has been made to incorporate habitat suitability. Habitat suitability has been considered as a koala value in later parts of the prioritisation process. In addition, the identification of areas of unoccupied habitat was not a focus of this project. The obvious limitation of this approach is that the recognition of ARKS is dependent on survey effort; where active survey is limited (particularly in the west of New South Wales), ARKS may be under-recognised. As more observation data are collected and collated, our understanding of the relative significance of koala occupied lands will evolve.

Table 2 List of ARKS with their basic characteristics. Also refer to Figure 5.

No.	Arks name	Region	Total area (ha)	Resilience	Security
1	Armidale	New England Tablelands	70,509	Low	Low
2	Banyabba	South Eastern Queensland	141,774	Moderate	Low
3	Barrington	NSW North Coast	166,660	Moderate	Low
4	Belmore River	NSW North Coast	48,027	Moderate	Low
5	Blaxland	Sydney Basin	24,800	Moderate	Low
6	Brisbane Water NP	Sydney Basin	12,817	High	High
7	Bungonia	Sydney Basin	353,546	Moderate	Moderate
8	Clouds Creek	NSW North Coast	115,417	High	Moderate
9	Coffs Harbour – North Bellingen	NSW North Coast	190,531	Moderate	Moderate
10	Comboyne	NSW North Coast	220,554	Moderate	Moderate

No.	Arks name	Region	Total area (ha)	Resilience	Security
11	Crowdy Bay	NSW North Coast	17,494	High	High
12	Far north-east	South Eastern Queensland	20,827	Low	Moderate
13	Far north-east Hinterland	South Eastern Queensland	339,862	Moderate	Moderate
14	Gibraltar Range	NSW North Coast	9,206	High	High
15	Girard – Ewingar	NSW North Coast	34,110	High	Moderate
16	Gunnedah	Brigalow Belt South	271,808	Low	Moderate
17	Hawks Nest	NSW North Coast	2,563	High	Low
18	Inverell	Nandewar	35,407	Low	Low
19	Karuah – Myall Lakes	NSW North Coast	18,817	Moderate	Moderate
20	Khappinghat	NSW North Coast	18,784	Moderate	Moderate
21	Killarney	Brigalow Belt South	16,507	Low	Low
22	Kiwarrak	NSW North Coast	34,911	Moderate	Moderate
23	Kwiambal NP	Nandewar	5,703	Moderate	Moderate
24	Lower Hunter	Sydney Basin	114,915	High	Moderate
25	Moree	Brigalow Belt South	23,598	Low	Low
26	Mt Pikapene	South Eastern Queensland	93,196	Moderate	Moderate
27	Murrah	South East Corner	82,402	High	High
28	Murray Valley	Riverina	10,491	Low	Moderate
29	Narrandera	NSW South Western Slopes	31,909	Low	Low
30	North Macleay – Nambucca	NSW North Coast	242,233	Moderate	Moderate
31	Nowendoc	New England Tablelands	42,505	Moderate	Moderate
32	Nullica	South East Corner	51,807	High	High
33	Numeralla	South East Highlands	116,699	High	Moderate
34	Pilliga	Brigalow Belt South	288,100	Low	High
35	Port Macquarie	NSW North Coast	25,140	Moderate	Moderate

No.	Arks name	Region	Total area (ha)	Resilience	Security
36	Port Stephens	NSW North Coast	49,322	Moderate	Moderate
37	Queen Charlottes Creek	South East Highlands	73,210	Low	Low
38	Severn River NR	New England Tablelands	12,102	High	High
39	Southern Clarence	South Eastern Queensland	63,164	Low	Moderate
40	Tweed Coast	South Eastern Queensland	15,634	Low	Low
41	Wallingat NP	NSW North Coast	37,798	High	Moderate
42	Wang Wauk SF	NSW North Coast	174,864	Moderate	Moderate
43	Wilson River	NSW North Coast	112,432	Moderate	Moderate
44	Wollemi NP	Sydney Basin	100,094	High	High
45	Woodenbong	South Eastern Queensland	175,702	Moderate	Moderate
46	North Grafton	South Eastern Queensland	59,755	Low	Moderate
47	Broadwater	South Eastern Queensland	13,913	Moderate	Moderate
48	Tweed Ranges	South Eastern Queensland	32,043	Moderate	Moderate

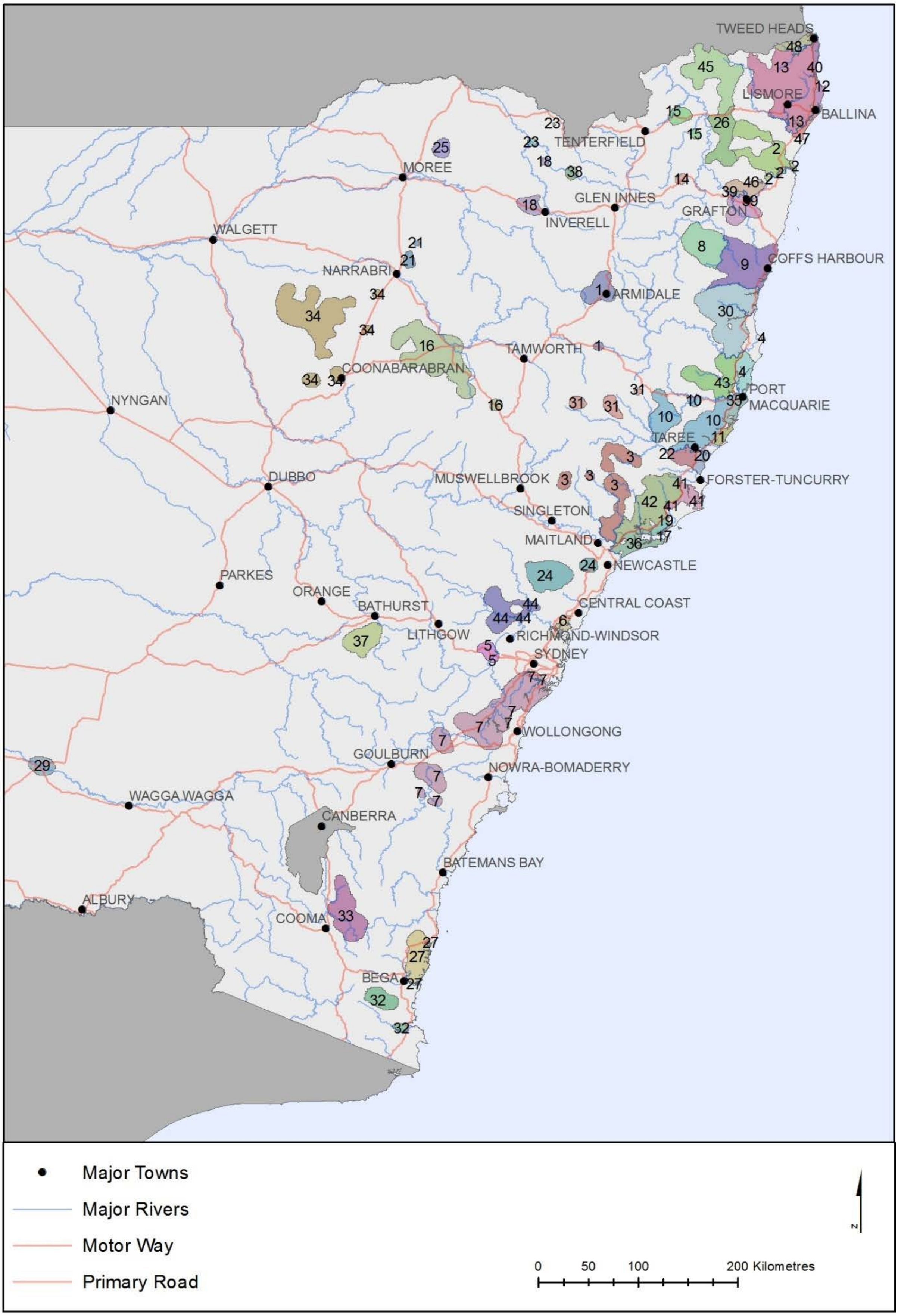


Figure 5 **Areas of Regional Koala Significance in New South Wales. Also refer to Table 2 for ARKS name and general information.**

Step 2: Identify threats to koala populations and associated risks of their decline

Rationale

Recent studies including an unpublished report to the NSW Department of Planning, Industry and Environment (Smith, Lunney and Moon 2016) identified a set of major threat groups which were described and ranked in terms of risk across bioregions of eastern Australia. A total of 14 threat groups were assigned, of which the majority were thought to be relevant to New South Wales. A panel of koala experts was asked to rank the past and future expected intensity of threats to koalas on a bioregional basis, from being absent to having a significant impact. The study predicted significant and increasing threats across several threat groups including those stemming directly from human activities (e.g. mining) and climatic threats (e.g. drought).

The threat groups identified by this study and others, including the Chief Scientist & Engineer's report (NSW Chief Scientist & Engineer 2016), have been used as a basis for the identification of threats and the development of strategies to spatially define and quantify their influence on koala occupancy and habitat values.

Scale of threat identification

The processes which drive threats to koala populations have a range of spatial scales, ranging from continental (e.g. climatic influences) to site level (e.g. vehicle strike and habitat loss). The recognition of the influence of scale when addressing threatening processes is an important consideration, as it helps to direct the kinds of mitigating actions which may be appropriate.

Site scale threats are those which can be observed and measured at a site or property scale. Mitigation strategies invariably require a site scale solution.

Area scale threats are often less measurable, but their effect is more obvious at an area (or regional) scale. Mitigation strategies often require coordinated programs (e.g. prescribed burning plans including ecological burning undertaken by groups including Firesticks[2] (Northern Star 2016)).

State scale threats are those which are difficult to observe or measure, even at the regional scale (such as drought or climate change). Mitigation strategies often involve state coordinated programs and research (e.g. climate change adaptation through AdaptNSW programs and resources) (OEH 2018a).

Outline of threat types

Nine distinct threat groupings have been identified for the purposes of this study to provide a framework for the spatial assessment of these threats across population areas in New South Wales. These threat groups have been drawn from a recent study undertaken for OEH (Smith, Lunney & Moon 2016) which outlined 14 separate threat groups across eastern

[2] An initiative that seeks to use burning practices developed by Aboriginal people to create ecologically resilient landscapes via communication pathways, education and on-ground land management.

Australia. The most relevant threat groups to New South Wales were selected and developed to form the basis of this study.

Table 3 below outlines the threat definitions, the scale of the process at which each threat operates and the range of values which would be expected to be impacted directly.

Table 3 Threat definitions for identified threats which can be prioritised using spatial mapping

Threat name	Threat definition	Reference	Scale of process	Values at risk
Habitat loss, fragmentation and degradation	The process of modification of ecosystems in such a way that reduces their capacity to support native species. This typically includes the loss, fragmentation and/or degradation of habitat. Fragmentation can be defined as the breaking apart of habitat, reducing the overall size of habitat and increasing the distance between patches such that the ability of fauna to move between them is reduced (Andrén 1994). Habitat degradation is where the quality of habitat is reduced over time. These three related processes may be caused by both natural and anthropogenic processes (Smith, Lunney & Moon 2016). For the purposes of the spatial prioritisation, urbanisation and mining development have been incorporated into this category.	SPRAT (DEE 2017) DECC 2008 Smith, Lunney, Moon 2016 OEH 2016a	Site	Forest maturity Landscape linkage Habitat suitability Refugia
Urbanisation (assessed as part of the above threats)	Urbanisation is the large-scale or incremental conversion of an area of land from a more natural state to dwellings and associated structures for the human population arising from expansion of towns and cities (Smith, Lunney & Moon 2016).	SPRAT (DEE 2017) Smith, Lunney, Moon 2016 DECC 2008 OEH 2016a	Site	Forest maturity Landscape linkage Habitat suitability Refugia
Collisions with motor vehicles	Collisions between koalas and motor vehicles are a widely documented regular occurrence in Australia. Busy roads in close proximity to occupied koala habitat are often a focus of concern by local councils and carer groups.	SPRAT (DEE 2017) Smith, Lunney, Moon 2016 DECC 2008 OEH 2016a	Site	Occupancy
Predation by wild or domestic dogs	Dog attacks on koalas are a significant cause of koala death and injury (DECC 2008). They are regarded as a threat across NSW, but particularly in populations in and around rural residential and peri-urban areas.	SPRAT (DEE 2017) Smith, Lunney, Moon 2016 DECC 2008 OEH 2016a	Site or area	Occupancy

Threat name	Threat definition	Reference	Scale of process	Values at risk
Wildfire and intense prescribed burns	Wildfire is a common and widespread natural and anthropogenic process in the eucalypt forests of Australia. The devastating effects of past intense wildfires on koala populations has been well documented. Prescribed fuel reduction burns carried out in the shoulder seasons may also cause canopy scorch, resulting in habitat loss and injury to koalas.	Smith, Lunney, Moon 2016 DECC 2008 OEH 2016a	Area	Occupancy Forest maturity
Drought	Drought (periods of abnormally low rainfall) is associated with koala decline in large areas of NSW, particularly in the west. Recent drought conditions in the Gunnedah area have caused koala populations to crash (Adams-Hosking & McAlpine 2017). Koalas are susceptible to climatic extremes, particularly heatwaves and droughts, which also affect the quality of nutrients and moisture available in their diet (Cork & Braithwaite 1996; Moore & Foley 2005).	SPRAT (DEE 2017) Smith, Lunney, Moon 2016 DECC 2008 OEH 2016a	Area or state	Occupancy
Heatwave	Heatwaves are defined as 'three days or more of high maximum and minimum temperatures that are unusual for that location' (Bureau of Meteorology 2018).	SPRAT (DEE 2017) Smith, Lunney, Moon 2016 DECC 2008 OEH 2016a	Area or state	Occupancy
Disease	Wild populations of koalas in NSW carry a number of pathogens that cause disease symptoms. The most common cause of disease in NSW is from the Chlamydiosis bacterium, which causes infertility, blindness and death (Polkinghorne et al. 2013).	SPRAT (DEE 2017) Smith, Lunney, Moon 2016 DECC 2008 OEH 2016a	Area	Occupancy
Reduction in suitability of habitat from the effects of climate change	The effects of anthropogenic climate change are expected to interact with a number of other threats to cause a significant, possibly severe, reduction in the suitability of habitat across NSW.	SPRAT (DEE 2017) Smith, Lunney, Moon 2016 DECC 2008 OEH 2016a	Area or state	Forest maturity Landscape linkage Habitat suitability Refugia

Mapping threatening processes across the landscape

Representing the spatial distribution of threatening processes across the landscape has been routinely undertaken in New South Wales over the last 20 years as part of regional conservation assessments (e.g. DECCW 2010b, DEC 2004). When appropriately used, mapping of threat risk can make a valuable contribution to the management of conservation values. The scale of determination of threat processes is integral both to strategies for mapping risk and interpreting that risk in a management framework.

Table 4 below summarises each of the threat groups by the mapping strategy applied, the estimated scale of determination (from the source data), then logically the confidence with which any determination of the accuracy of that assessment can be made. It is important to note that all analysis datasets have been rescaled to 500-metre grids for the purposes of analysis consistency. The scale of determination, therefore, is based on the spatial integrity of the source data. A detailed profile of each threat class is provided in Appendix D.

Table 4 Threat groups, mapping strategy, scale of determination and confidence

Threat name	Threat mapping strategy	Scale of determination	Confidence of determination
Habitat loss, fragmentation and degradation	Assignment of risk likelihood classes to recognised contributing landscape processes. These processes include: clearing of native vegetation clearing history land capability and suitability timber harvesting state forest FMZ private native forestry activity mining exploration active mining leases exploration areas land use land zoning and tenure.	Site	Moderate
Urbanisation (assessed as part of habitat loss, fragmentation and degradation)	Assignment of risk classes to land identified for urban, commercial or industrial expansion, including: areas identified by the recently released regional plans as new release or investigation areas currently zoned as urban, industrial, commercial or large lot residential.	Site	High
Collisions with motor vehicles	Data collected from the BioNet database often contains roadkill or road injury information which can be used to develop risk classes for hotspots of high mortality and road types which have high rates of collision. Habitats in proximity to roads are assigned risk according to the risk score of the road category.	Site	Low

Threat name	Threat mapping strategy	Scale of determination	Confidence of determination
Predation by wild or domestic dogs	Spatial analysis of BioNet data recorded as a dog attack or near miss showed that the bulk of interactions (80%) were clustered within 200 m of urban or rural residential zoned land. These areas are categorised as high risk. Rural lands are still of moderate risk, with the remaining 20% of attacks occurring within 5 km of a dwelling.	Area	Low
Wildfire and intense prescribed burns	Fire intensity is closely associated with fuel loads. The NSW RFS modelled fuel loads for NSW using the Phoenix Rapidfire decision support tool which considers time since fire, vegetation type and fuel accumulation parameters.	Area	Moderate
Drought (not mapped)	Drought risk modelling is not currently available for NSW. No suitable surrogates for this risk category have been located.	Area or state	N/A
Heatwave	The NARCliM climate modelling project provides a range of predictive models of risk for current and future high maximum temperature (35+°C) frequency. Using these as a surrogate for heatwave likelihood, heatwave risk classes have been assigned.	Area or state	Moderate
Disease	Wildlife rehabilitation carer data, collected and processed by OEH from a range of community groups throughout NSW, has recorded rates of disease occurrence throughout koala populations in NSW (by postcode). Although not spatially explicit, this data provides a regional indication of relative risk for koala populations.	Area	Moderate
Reduction in suitability of habitat from the effects of climate change	Modelled data provided by the University of Melbourne maps relative likelihood of decline in habitat suitability for the koala across eastern Australia. Modelled suitability compares current period suitability with 2060–2079. Risk classes are assigned from the relative decline in modelled habitat.	Area or state	Low

Step 3: Identify the values of koala populations in New South Wales requiring protection from the identified threats

Rationale

Available literature on koalas identifies a range of landscape values which are important for the persistence of koala populations. Spatial identification of how these values are distributed across the landscape is an important step in assessing the level of threat that they may be exposed to by threatening processes identified in Step 2 (Identification of threats to koala populations).

A value profile of each ARKS will help build a picture of the resilience of that population to the threats operating in that landscape. This section identifies koala landscape values as identified by available data across New South Wales.

Scale of value identification

The spatial identification of koala values across the NSW landscape has been undertaken to be consistent with the threats assessment. As with the threats mapping, the values mapping has been derived using a collation of datasets from a variety of spatial scales ranging from extant vegetation (5 m raster) through to koala likelihood of occurrence (10 km grid in the west). Details of how each dataset has been included and resampled (where appropriate) are included under Step 4 below.

Outline of value types

Five value groups have been identified by this process which have some capacity for spatial recognition and mapping.

The spatial scale and reliability of mapping for these values is variable. The confidence of each value estimate needs to be accounted for in the assessment process. As with threat mapping, the scale of determination for each of the value mapping datasets is reflected in the final confidence assigned.

Table 5 below summarises each of the values for assessment, their scale of determination and the assigned confidence class. A detailed profile of each value class is provided in Appendix D.

Table 5 Threat definitions for identified threats that can be prioritised using spatial mapping

Value name	Value definition and analysis strategy	Reference	Scale of determination	Confidence of determination
Forest maturity	The structure of the forest canopy has been demonstrated to be linked to preference by koalas, with usage by koalas most common in trees of mature and senescent growth stages (over 30 cm diameter at breast height).	Smith 2004	Area	Low

Value name	Value definition and analysis strategy	Reference	Scale of determination	Confidence of determination
	Landsat TM vegetation change data since 1988 has been used to estimate regrowth forest extent. Forest not identified as regrowth or cleared is assumed to be mature. Higher value is given to mixed age and mature forest.			
Habitat connectivity and integrity	The distribution of habitat as measured by patch size has been found to be an important measure of occupancy by koalas. Vegetated linkage areas are important for koalas to survive. Where dispersal and recruitment are impeded by barriers such as open areas and roads, koala populations would be expected to decline (DECC 2008). Native woody vegetation was analysed for patch size and classified according to recognised important size thresholds, with larger patches considered of higher value.	DECC 2008	Site	High
Habitat suitability	The current SEPP44[3] defines potential habitat as vegetation communities with greater or equal to 15% canopy composition of koala feed trees. Vegetation classes of NSW were reviewed for feed tree likelihood (class descriptions are outlined in Keith 2004). Habitat suitability classes were assigned to each vegetation class.	DoP 1995 DECC 2008	Area	Moderate
Refugia	Access to permanent water in times of drought and heat stress is considered an important landscape feature. Mapping of permanent water across NSW has been undertaken with relative precision within the NSW Digital Terrain Database (DTDB) which denotes feature types (perennial versus ephemeral) and natural versus man-made. Patches of vegetation contiguous with perennial streams have	DEE 2017 Crowther et al. 2014	Site	High

[3] State Environmental Planning Policy (SEPP) 44 – Koala Habitat Protection

Value name	Value definition and analysis strategy	Reference	Scale of determination	Confidence of determination
	been mapped. Large patches of habitat with access to water are valued highest.			
Occupancy	Likelihood of occurrence of koalas as estimated by probability of occurrence (OEH 2015a). Density of occupation by koalas varies substantially, with high fertility landscapes having a higher possibility of high density populations. The most complete, accurate map of koala likelihood of occupation is the 'Koala likelihood of occurrence' map (OEH 2015a). For analysis purposes, occupancy of koalas within ARKS is assumed.	OEH 2015a	Area	Moderate

Step 4: Quantify the risks posed to koala values by the threats

Assignment of risk classes

It is consistent with recommended NSW Government practice to assign relative risk rankings to identified threats. Table 6 presented below is a standard risk assessment matrix, used to relate the likelihood of a threat event occurring to the consequence of the event, to ascribe a level of risk.

The risk parameters were designed to be applied over the timeframe of the SoS Iconic Koala Project, which aims to secure the koala in the wild for the next 100 years. Therefore, the likelihoods of threat events have been scaled to take account of longer-term threats such as the impacts of climate change on habitat suitability.

Table 7 and Table 8 respectively define the likelihood and consequence criteria used to derive the risk classes in Table 6. While current models for climate change and climatic variables do not extend over the 100-year timeframe, both NARCliM (OEH 2016b) and Briscoe et al. (2016) models extend to the period 2060–79 (approximately 50 years).

Assessing the level of risk to koala values associated with threatening processes is a key step in prioritising appropriate conservation actions outlined in the action toolbox, which seeks to address the full range of social, economic and environmental threats to koala populations.

Table 6 Risk assessment matrix

Likelihood	Level of risk				
Almost certain	Minimal	Low	Moderate	High	Very high
Likely	Minimal	Low	Moderate	High	High
Possible	Minimal	Minimal	Low	Moderate	High
Unlikely	Minimal	Minimal	Minimal	Low	Moderate
Rare	Minimal	Minimal	Minimal	Minimal	Low
Consequence level	Insignificant	Minor	Moderate	Major	Catastrophic

Table 7 Likelihood level and definition

Likelihood level	Definition
Almost certain	Expected to occur regularly throughout each year
Likely	Expected to occur multiple times per year
Possible	Not expected to occur annually, but expected within a 5-year period
Unlikely	Not expected to occur within the next 5 years, but expected within a 20-year period
Rare	Not expected to occur within the next 20 years, but expected within a 100-year period

Table 8 Consequence level and definition

Consequence level	Definition
Insignificant	The impact of the threat event, where present, has no discernible effect on koala populations, either locally or at a wider level.
Minor	The impact of the threat event has no discernible effect on koala populations at a wider level. Some localised effects may be present.
Moderate	The impact of the threat event has a moderate effect on wider populations, with a relatively short (5–10 year) recovery period.
Major	The impact of the threat event has a major effect on wider populations, with a relatively long (10–20 year) recovery period. Localised extinctions are possible.
Catastrophic	The impact of the threat event has a catastrophic effect on wider populations, with an intergenerational (20+ years) recovery period. Wider extinctions are possible.

The threat versus consequence matrix

It is an accepted fact that not all threatening processes have the same consequence when considered across the range of values important to koalas and koala habitat. For instance, vehicle collisions have a high level of consequence to occupancy (koala individuals within a population), but no measurable consequence on forest maturity. Conversely, habitat loss and fragmentation have a major effect on connectivity and forest maturity, but a much lesser **immediate** effect on occupancy, though the longer-term effects of habitat loss will eventually cause a reduction in koala numbers through associated threatening processes.

Table 9 below designates the level of consequence for a threat event to each of the identified koala values. Using these assigned consequence categories and mapped likelihood categories (from the threat mapping), a risk range for each threat/value combination has been assigned (refer to Appendix B). For instance, the risk range to forest maturity from vehicle collision is insignificant, regardless of the likelihood, whereas the risk to occupancy from vehicle collision ranges from minimal (rare likelihood) to high (almost certain).

Appendix B contains the final risk categories that will be used to apply numerical modifiers to mapped koala values to determine their resilience to current and future threats. The method for determining how resilience is calculated as outlined in Step 5.

Table 9 Consequence mapping for threat groups and koala values

Threat group	Consequence score				
	Forest maturity	Refugia	Connectivity & integrity	Habitat suitability	Occupancy
Habitat loss, fragmentation and degradation	Major	Major	Major	Major	Moderate
Collisions with motor vehicles	Insignificant	Insignificant	Major	Insignificant	Major
Predation by wild or domestic dogs	Insignificant	Insignificant	Major	Insignificant	Moderate
Wildfire and intense prescribed burns	Major	Minor	Minor	Minor	Major
Drought	Insignificant	Insignificant	Insignificant	Insignificant	Major
Heatwave	Insignificant	Insignificant	Insignificant	Insignificant	Major
Disease	Insignificant	Insignificant	Insignificant	Insignificant	Moderate
Reduction in suitability of habitat from the effects of climate change	Insignificant	Major	Insignificant	Catastrophic	Catastrophic

Step 5: Quantify the likely resilience of koalas to the identified risks

Rationale

An understanding of the relative risk and resilience of areas of significance for koalas is useful in helping to guide how actions are prioritised across these areas in New South Wales. The resilience of ARKS, as defined in this report, is a function of the values (habitat and occupancy) and the level of risk they are exposed to by threatening processes.

Resilience has been quantified spatially (determined for each ARKS as measured from functional habitat) by analysing the risk mapping and value mapping within a matrix of weighted modifiers to give an overall estimate of likely persistence. In addition to resilience, ARKS security has been assessed as a function of predicted sensitivity to loss and the land tenure status of koalas. These measures are designed to be a surrogate for a viability assessment in lieu of accurate koala population data.

Resolution, assumptions and sampling bias

To undertake a spatial analysis of this type, a number of assumptions regarding the use of data have been made. Key decisions regarding the spatial scale, the type of datasets to include and the way each is incorporated, have been informed by the Spatial Dataset Audit (Rennison 2017a) and by preceding studies concerning risk analysis processes. The details of how each dataset has been used in the analysis and its limitations have been included in the profiles of values and threats (Appendix D).

Spatial scale

Resilience values have been calculated on a grid square basis at a nominal resolution of 500 metres. This resolution has been determined as the minimum scale which can account for the spatial variability of the component threat and value datasets which make up the analysis. An important consideration for this decision was home range movements of koalas across their range. The analysis grid resolution (500 m) has been chosen to represent a median coastal koala female home range, estimated to be 25 hectares.

Risk surfaces from linear and fine-scale threats (such as roads) are only able to be represented at fine-scale; however, climatic risk surfaces such as heatwave are only available at a continental scale.

Temporal scale

The temporal scale of the resilience analysis has been set nominally at 50 years. This scaling has been applied through the likelihood class rankings and constrained by available data, notably the climate change modelling (Briscoe et al. 2016) and the NARCliM modelling of climatic variables (OEH 2016b).

Selection of threat and value criteria

A number of sources of information were consulted in the selection of criteria for analysis of threats and values. Major studies consulted in the process of criteria selection include:

Koala Threat Mapping for Conservation Management, Interim Report to the NSW Office of Environment and Heritage, 16 June 2016 (Smith, Lunney & Moon 2016)

Recovery plan for the koala (*Phascolarctos cinereus*), November 2008, Department of Environment and Climate Change (DECC 2008)

Species Profile and Threats Database (SPRAT) profiles (DEE 2017)

Threatened Species Scientific Committee determination (DSEWPAC 2012).

Other studies used in the formulation of threat and value mapping are referred to in each profile outlined in Appendix D.

Sampling bias

It is well recognised that only a small proportion of mapped or modelled koala habitat has been subject to adequate survey. Of the approximate 22,000 records of koalas in New South Wales since 1990, the majority are derived from non-stratified or non-systematic survey, with the largest single contributor being default ATLAS sightings at over 7000 records. As a result, there is a low degree of confidence in koala likelihood of occurrence for large parts of New South Wales (OEH 2015a). With this clear bias of survey effort in mind, it is important that resilience measures are viewed in the context of the confidence ranking for each likelihood of occurrence grid (OEH 2015a). Each resilience profile map displays areas of low confidence (or no data) to highlight areas where there is a high degree of uncertainty around koala occupancy information.

Values scoring for integrity mapping

Values scoring for ARKS has been undertaken against five criteria outlined in Table D.1 and detailed in Appendix D, *Values assessment profiles.* Each value criterion contributes equally to the final values integrity score for an area, as each of the criteria are considered of high importance to koalas.

It is accepted that the mapping presented in this framework is regional in nature and is suitable only for strategic planning purposes. Local planning documents such as Comprehensive Koala Plans of Management, where they exist, are the most appropriate resource for assessing koala values at the property scale.

The values integrity mapping has two proposed roles in the framework for koala prioritisation:

Current value of areas for koala conservation

The values integrity score provides an overall relative measure of an area's capacity for contributing to koala conservation through security of habitat and koala populations. The areas represented as high and very high value should be considered important for retention as koala habitat.

Contribution to the calculation of resilience for areas of regional significance

Values integrity mapping provides an important step in determining the resilience of ARKS. The integrity mapping provides a baseline measurement of koala values against which threatening processes are analysed to determine functionality of habitat (see Figure 6 below).

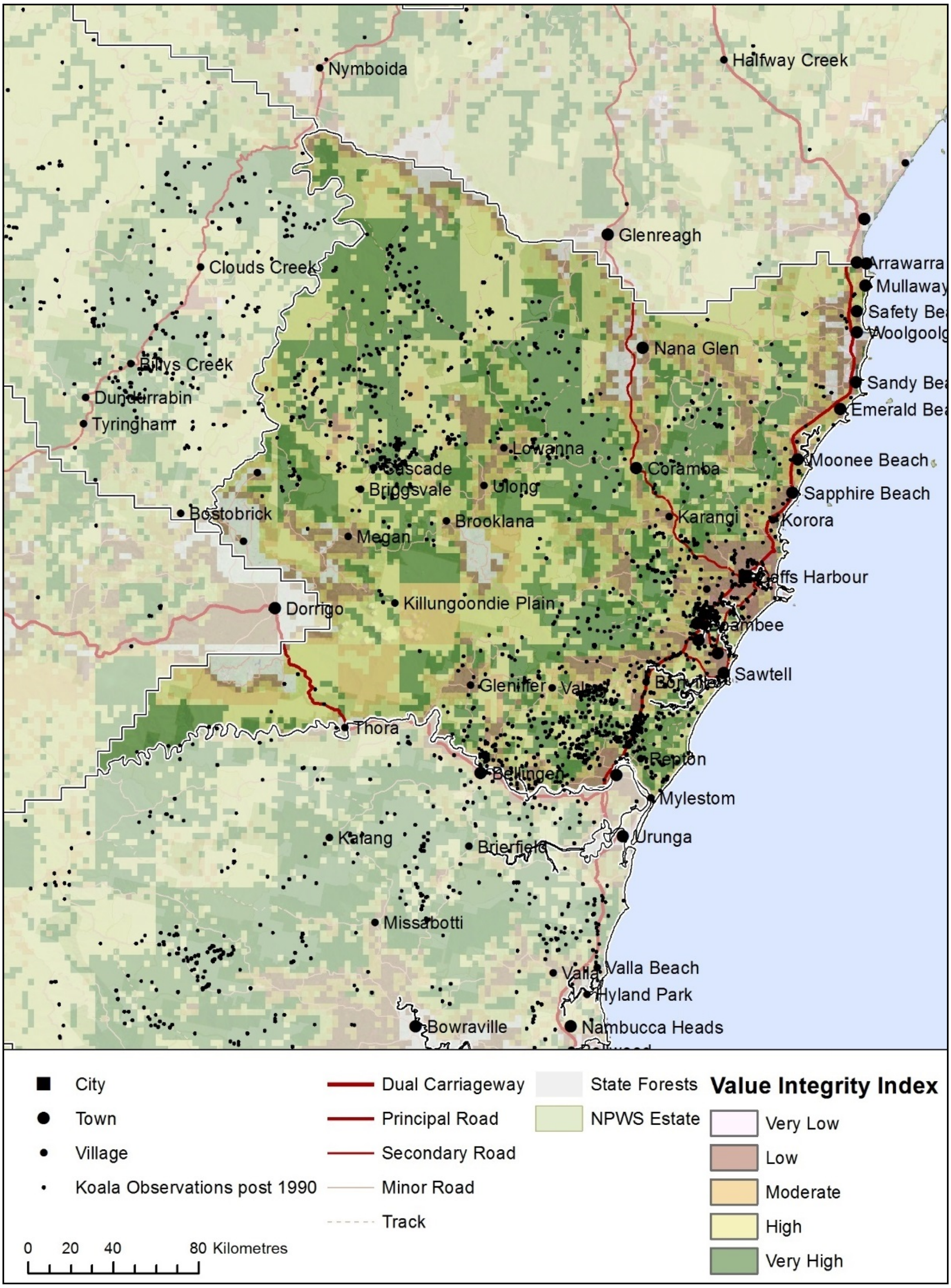


Figure 6 Values integrity mapping example, Coffs Harbour – North Bellingen

Resilience class and security for Areas of Regional Koala Significance

The resilience class is an area scale measure of the future predicted ability of koala areas to withstand loss of habitat and occupancy from threatening processes. The resilience and security measures are modelled using the functional habitat classification in a three-step process:

1. calculation of the functional habitat score for each 500 m grid cell (site scale)
2. allocation of a resilience class to each ARKS
3. allocation of a security class based on the overall quantity of functional habitat within the ARKS.

The resilience class is a representation of the likely future persistence of each ARKS based on assumptions of threat level from current information and future modelled climatic predictors (e.g. NARCliM (OEH 2016b); Briscoe et al. 2016).

As accurate koala population information is not widely available across New South Wales, resilience class is not a measure of population viability; that is, a low resilience class does not translate directly to a low viability population, although, in the absence of accurate population data, it is intended to serve as a broad surrogate.

Calculating site scale functional habitat in an ARKS

Functional habitat is defined within the framework as being land which is expected to be able to support koala populations into the future, given current assumptions of threatening processes. For the purposes of calculating resilience at an area scale, only two classes of functionality are recognised. For the purposes of visualisation within profile areas, all four analysis classes are represented on the resilience maps.

The functional habitat for an area of land (calculated on a 500 m grid square basis) is estimated through the application of a series of spatial modifiers which are the expression of the risk level for that area. Appendix C illustrates how each risk layer impacts differentially on each of the mapped value layers. The degree of impact of each threat layer on each value has been determined through a series of assumptions recorded in Table 9 (threat consequence) and likelihood mapping in Appendix D. Calculations for each grid square are made on the spatial correspondence of the mapped risks with the mapped values.

Risks for threatening processes are cumulative and therefore modifiers are multiplied for each risk that is impacting on a value. Standard modifier values for each risk class have been developed and are presented in Table 10. The modifiers represent the likely reduction factor, due to each threat risk, of mapped koala values over the scenario period (50 years).

Table 10 Risk level and spatial modifier scores

Risk level	Spatial modifier
Minimal	1.0
Low	0.85
Moderate	0.65
High	0.5
Very high	0.2

Once the risk modifiers have been applied and resilience scores calculated, each grid cell is then classified as either **Moderate – High functionality** or Low – Very low **functionality**, as described in Table 11 below. The purpose of this classification is to distinguish between lands which have the capacity to support koala populations in the long-term, and those where, with current threatening processes, koalas are not expected to persist.

The process for calculation of resilience is represented below. The risk modifiers (R_x) are applied to each value (V_x), and these are then summed and rescaled (0–5). Weightings were applied to each of the value scores, with higher weightings given to koala occupancy and habitat suitability (1.5), and lower to forest maturity and landscape integrity (0.5). These weightings were applied in consideration of the relative importance of each value criterion to the persistence of koalas. The resilience calculation was undertaken for every 500-metre grid cell in the analysis area (eastern New South Wales).

RESILIENCE $CELL_x$ = V_{FM} $(R_{HL}*R_F*R_{VS}*R_{DA}*R_{Di}*R_{HS}*R_{CC})W_{FM}$
{forest maturity value with risk modifiers}

+ V_{LI} $(R_{HL}*R_F*R_{VS}*R_{DA}*R_{Di}*R_{HS}*R_{CC})W_{LI}$
{landscape integ. value with risk modifiers}

+ V_{HS} $(R_{HL}*R_F*R_{VS}*R_{DA}*R_{Di}*R_{HS}*R_{CC})W_{HS}$
{habitat suitability value with risk modifiers}

+ V_{RR} $(R_{HL}*R_F*R_{VS}*R_{DA}*R_{Di}*R_{HS}*R_{CC})W_{RR}$
{riparian refugia value with risk modifiers}

+ V_{KO} $(R_{HL}*R_F*R_{VS}*R_{DA}*R_{Di}*R_{HS}*R_{CC})W_{KO}$
{koala occup. value with risk modifiers}

where:

V_{FM} = value score for forest maturity

V_{LI} = value score for landscape integrity

V_{HS} = value score for habitat suitability

V_{RR} = value score for riparian refugia

V_{KO} = value score for koala occupancy

R_{HL} = risk modifier for habitat loss & fragmentation

R_F = risk modifier for fire

R_{VS} = risk modifier for vehicle strike

R_{DA} = risk modifier for dog attack

R_{Di} = risk modifier for disease

R_{HS} = risk modifier for heat stress

R_{CC} = risk modifier for climate change

W_{FM} = weighting for forest maturity

W_{LI} = weighting for landscape integrity

W_{HS} = weighting for habitat suitability

W_{RR} = weighting for riparian refugia

W_{KO} = weighting for koala occupancy

Table 11 Functional habitat categories

Functionality level	Functional habitat score	Resilience level	Map code	Characteristics
Moderate – High functionality habitat	2.0 – 5.0	Moderate – High	High (3.5 – 5.0)	Koala habitat that has a moderate to high level of integrity and future expected resilience based on current and projected risk from mapped threats.
			Moderate (2.0 – 3.5)	
Low – Very low	0.0 – 2.0	Low	Low (1.0 – 2.0)	Koala habitat that has a low level of integrity and future expected

Functionality level	Functional habitat score	Resilience level	Map code	Characteristics
functionality habitat			Very low (0.0 – 1.0)	resilience based on current and projected risk from mapped threats.

Allocating a security class for each ARKS

ARKS were ranked according to the security afforded by both conservation management and the overall extent of functional habitat within the ARKS.

Conservation management analysis

The extent of conservation management has been measured in terms of the relative proportion of koala observation records on both formal and informal reserve. Each ARKS was classified as one of three reservation categories:

High reservation	**>50% of records within conservation management**
Moderate reservation	**30–50% of records within conservation management**
Low reservation	**<30% of records within conservation management**

The categories of conservation management lands included in the reservation assessment analysis are:

- national park estate
- conservation agreements (VCAs)
- wildlife refuges
- Indigenous protected areas
- registered property agreements (in perpetuity)
- Nature Conservation Trust – conservation covenants
- biobanking agreements
- other private conservation agreements include Bush Heritage Australia and Australian Wildlife Conservancy
- property vegetation plan (PVP) incentive lands
- PVP offset lands
- PVP conservation lands
- flora reserves
- southern mallee reserves.

Sensitivity to loss analysis

The sensitivity to loss within each ARKS has been estimated by assessing the availability of functional habitat to support a minimum population of 50 breeding females (ELA 2014). For this analysis, a variable assumption of home range was adopted, with females in southern ARKS assumed to have a home range of 175 hectares. By comparison, north coast and hinterland ARKS were assumed to have a home range of 20 hectares. Although variable, western and Sydney Basin ARKS were assumed to have a home range of 30 hectares and tablelands ARKS were given a nominal home range of 25 hectares. These figures were collated through internal OEH advice, expert advice (pers. comm. Stephen Phillips 2017) and available literature (Paull & Hughes 2016).

ARKS determined to have a high sensitivity to loss are typically fragmented areas with a reduced capacity to support koala populations. These areas are often subject to elevated threat levels depending on the spatial and site level context.

ARKS identified as having a low sensitivity to loss are characterised as having greater overall quantity of functional habitat and connectivity, which puts them at a low risk of population collapse. High sensitivity to loss ARKS are commonly smaller in size; however, this trend is not uniform and many larger western ARKS have a high sensitivity to loss because of compounding threats.

Table 12 summarises the criteria for each sensitivity to loss class.

Table 12 Areas of Regional Koala Significance – sensitivity to loss classes

Sensitivity class	Sensitivity criteria
High sensitivity to loss	Less than the area of (moderate or high) functional habitat modelled to support a population of 50 females
Moderate sensitivity to loss	More than the area of (moderate and high) functional habitat modelled to support a population of 50 females
Low sensitivity to loss	More than twice the area of (moderate and high) functional habitat modelled to support a population of 50 females

Calculating the security of an ARKS

Having calculated the sensitivity to loss and reservation level of each ARKS, the security is allocated from the matrix below (Table 13), a relative measure from high to low. Secure areas are deemed to be areas of larger size and functionality, where a higher proportion of koalas are recorded within lands managed for conservation. Low security areas, conversely, are those which are smaller, have a lower overall functionality, and in which a higher proportion of koalas are recorded outside lands managed for conservation.

Table 13 Matrix to determine security classes of Areas of Regional Koala Significance

	Reservation level (based on koala records of occurrence)		
Sensitivity to loss	**High** (50% records in reserve)	**Moderate** (30–50% records in reserve)	**Low** (<30% records in reserve)
Low	High	High	Moderate
Moderate	High	Moderate	Low
High	Moderate	Low	Low

Allocating a resilience class for each ARKS

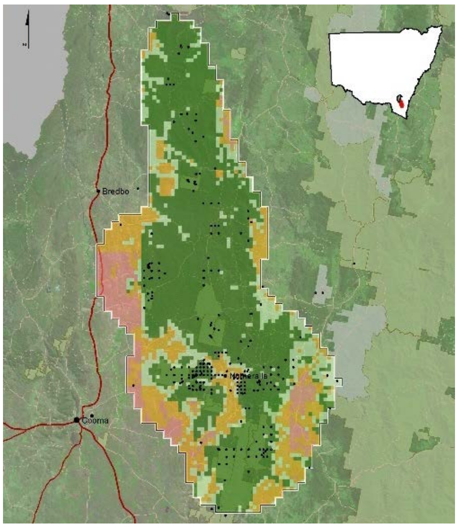
For each ARKS, a resilience class has been allocated using a simple classification of the predicted functionality of habitat within the defined area. There are three resilience classes, which are defined in Table 14.

Table 14 Areas of Regional Koala Significance resilience classes

Resilience class	Resilience criteria	Characteristics
High resilience population	70% or higher (Moderate – High) functional habitat	Consolidated population with stable and secure land use, either managed for conservation or with dominantly passive use. Other threats have low to moderate influence. Active mitigation of threats not typically required. May be suitable for conservation management.
Moderate resilience population	30–70% (Moderate – High) functional habitat	Partially fragmented, but still retaining significant areas of functional habitat. Typically, mixed land use requiring active mitigation in some areas. Priority for acquisition for conservation and BCT investment.
Low resilience population	Less than 30% (Moderate – High) functional habitat	Highly fragmented, retaining only pockets of functional habitat. Occurring in landscapes which have intense land use practices (generally agriculture in the west and urbanisation on the coast). Priority for site-based threat mitigation and landscape strategies to protect, restore and connect habitat.

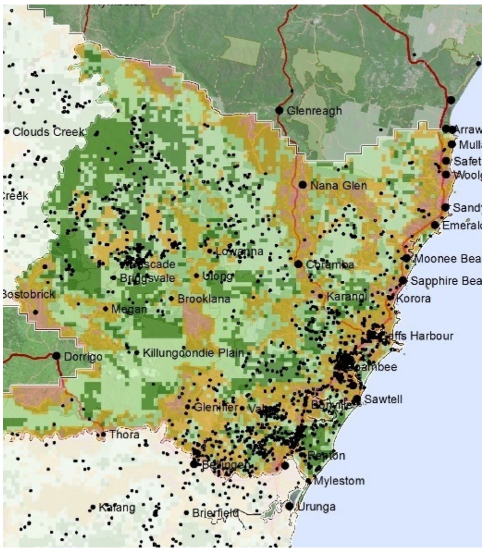
Table 15 below gives three examples of ARKS classified as High, Moderate and Low resilience, together with a brief account of land use and dominant threats. The full profiles for each area are provided in Appendix A.

Table 15 Example Areas of Regional Koala Significance with resilience class allocation

ARKS name: Numeralla		
Resilience class	High	
Security	Moderate	
Characteristic land use	Passive with some conservation management	
Dominant threats	Fire	

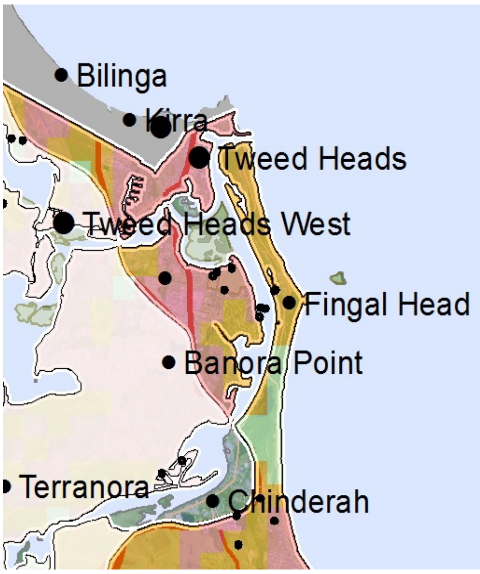
ARKS name: Coffs Harbour – North Bellingen

Resilience class	Moderate
Security	Moderate
Characteristic land use	Mixed. Conservation management, forestry, rural and urban
Dominant threats	Habitat fragmentation, dog attack



ARKS name: Tweed Coast – North

Resilience class	Low
Security	Low
Characteristic land use	Mixed. Conservation management, forestry, rural and urban
Dominant threats	Dog attack, habitat fragmentation, vehicle strike



Step 6: Identify the most appropriate strategies within the action toolbox to effectively mitigate threats in each area

Rationale

The Saving our Species Iconic Koala Project identifies a set of actions to address critical threats to the koala, which has been termed the **action toolbox**. The actions have been designed to address the broad range of threats operating on koalas in the NSW landscape, through a variety of approaches including support for community carer groups, scientific research, improved coordination of land management activities, improvement in the standard, coverage and maintenance of core koala datasets, and the support of programs to restore and increase the area of koala habitat in land demonstrated to have koala populations.

To effectively and efficiently mitigate threats to koala areas, actions should reflect the management capabilities of land managers and be assigned as such. Furthermore, land managers can seek to acquire land, enter into partnerships or apply management strategies to protect local populations.

The action toolbox

For each of the prescribed actions in the action toolbox, a scale of operation has been assigned, which indicates the relationship of the activity to the landscape; the three scales being site, area and state.

Site	Activity is targeted to a specific property or location, where an on-ground activity is being undertaken. Benefits are directed to that location and are typically able to be measured over time.
Area	Activity is targeted to a local community or local government area. Benefits are directed with a broader focus to the local population or community.
State	Activity has a state level focus, often to improve understanding of koalas and the development of strategies to better manage resources. Benefits are directed statewide.

The objectives of the spatial prioritisation of SoS koala projects is focused on assisting to prioritise those actions which operate at a **site** or **area** scale. The full set of actions from the action toolbox are shown in Table 16.

Table 16 Saving our Species Iconic Koala Project action toolbox

Threat	Action description	Scale
Loss, modification and fragmentation of habitat	In areas where a koala population is present, undertake restoration works to improve the quality and increase the area of koala habitat. Restoration and augmentation works may include bush regeneration, fencing, weed and pest control, augmentation planting and/or direct seeding in areas of degraded and/or potentially suitable habitat. Appropriate feed and shelter tree species should be used in revegetation works. Restoration works should focus on expanding existing smaller areas of known occupied habitat, including private land, and connecting areas of suitable habitat to create	Site

Threat	Action description	Scale
	corridors for movement. Resources for long-term monitoring and management of restored areas should be included.	
	In areas where a koala population is present, negotiate agreements with landholders, particularly in perpetuity covenants or stewardship agreements that promote the protection and retention of high-quality koala habitat or habitat that contributes significantly to connectivity in the landscape.	Site
	In areas where a koala population is present, undertake koala habitat studies and mapping using standardised methods and terminology to identify key koala populations, and rank and map koala habitat.	Site, area
Vehicle strike	Identify blackspots where koala road mortalities are greatest and target proven mitigation techniques such as fencing and wildlife crossings, in discussion with council and Roads and Maritime Services. Mitigation may also involve the development, testing and deployment of new technologies that can reduce vehicle strike.	Site
	Liaise with Roads and Maritime Services and local councils in the development of new/existing roads to plan koala barrier fencing and crossings as part of road construction projects.	Site
Predation by wild or domestic dogs	Conduct local community awareness campaigns in areas where attacks by domestic dogs on koalas are prevalent to raise awareness of the impacts and the importance of responsible dog ownership, including keeping dogs restrained on leads and in properly fenced enclosures.	Area
Intense prescribed burns or wildfires that scorch or burn the tree canopy	Liaise with relevant authorities or land managers to ensure that identified koala habitat areas are defined as assets for protection in fire planning tools when managing wildfires and prior to any hazard reduction burns. Promote best practice fire management protocols in areas of significant koala populations.	Area
	Liaise with authorities or land managers to ensure that any unavoidable prescribed burns within koala habitat are conducted in a way that minimises impacts on koala habitat and individual koalas, based on best practice guidelines.	Site, area
Koala disease	Improve understanding of the role of chlamydia and other diseases in koala population dynamics and mortality, including baseline genetic information and links between habitat disturbance and disease-related morbidity, by conducting research in collaboration with universities, vets and ecologists.	State
Heat stress through drought and heatwaves	Support carer and vet networks in their response to the management of koala health and welfare during extreme weather conditions.	Area, state
	Research and trial adaptation management actions such as the installation of artificial water sources and the establishment of refuge habitat and promote connectivity through habitat restoration.	Site, area
Human-induced climate change	Use predicted climate change data and modelling techniques to predict the possible impacts on koalas from climate change. This should include how koala habitat is likely to	Area, state

Threat	Action description	Scale
	change under different climate change scenarios, such as temperature rise impacts on habitat, drought and wildfires. Use this information to prioritise adaptation actions and investment in habitat and corridor protection and restoration.	
Inadequate support for fauna rehabilitation	Support koala rehabilitation groups and vets to rehabilitate sick and injured koalas through training, provision of materials, and promotion of statewide protocols including for rehabilitation, genetic profiling, record-keeping and release to the wild.	State
Lack of knowledge (poor understanding of sources of trauma and mortality)	Engage with koala rehabilitation groups and other information sources to better understand the causes of koala trauma and mortality. Collate and map the results.	State
Lack of knowledge (poor understanding of population distribution and trend)	Develop standardised methods and reporting for monitoring change in koala populations and distribution through time and contribute survey data to centralised database. Include genetic information where possible.	State
	Support the collation of koala survey records and monitoring information through a centralised database for statewide reporting and analysis, contributing records to NSW BioNet.	State
Lack of knowledge (poor understanding of animal movements and use of habitat)	Improve understanding of koala movements and use of their habitat in the landscape by conducting targeted research on individuals using GPS collars and mark-recapture techniques.	Area
Getting the community engaged in koala conservation	Use multiple channels to engage the community in koala conservation and recovery actions across the State. This includes communication strategies, citizen science, volunteers, on-ground conservation actions, awareness programs, and landholder engagement.	State

Assigning priority actions using security and resilience

Context

There is a need to provide regional scale guidance for *Saving our Species* project managers and other stakeholders in the status and future expected persistence of koala occupied areas in New South Wales.

The following information is best used to guide prioritisation of actions at the regional scale. While the metrics provided in this report give a meaningful representation of expected koala resilience, threats and security, the results cannot be directly interpreted at a site scale. Decision-making at the local and site scale must always be guided primarily by the best available local information, including Koala Plans of Management (where they exist), other relevant local plans, and advice from recognised local experts.

Security versus viability

Identifying populations with a high security can be best achieved if accurate estimates of population size and recorded occurrence information are available. The Koala Spatial Dataset Audit (Rennison 2017a) identified only limited population size information, mainly associated with koala habitat studies for Comprehensive Koala Plans of Management. This information was generally collected at a local scale and cannot easily be translated up to the regional scale. Some regional population estimates are available for the north coast, however, these estimates (Scotts 2013) have a very wide margin of error. Koala observation data, while extensive, is still heavily biased towards areas of high population density (around townships) and lands with a requirement for survey (e.g. state forests).

The security classifications have been provided as a broad surrogate of the potential vulnerability of koala populations in an area in lieu of accurate population data at a regional scale. Users should be aware that these classifications are based on current koala record data and expected koala occupancy with assumptions of home range information.

Setting priorities using resilience class and security

ARKS have been classified into three broad categories for the purposes of prioritising actions. The classification (presented in Table 17 below) is based primarily on resilience and security, but also considers the nature of threats which are acting on the ARKS.

The prioritisation of actions should be made in consideration of the scale at which (and by what mechanism) threats to the area can be mitigated. Threats which can be mitigated at the site or area scale are listed in the action toolbox (Table 16 above). Threats which can be mitigated by land use change are more easily determined at the property scale, but typically include habitat fragmentation and may also include wildfire, dog attack and vehicle strike.

Threats driven by climatic influences such as heat stress and climate change are difficult to mitigate through site and area scale actions. Mitigation of site and area scale threats in landscapes with high predicted climatic threats may help to reduce the overall stress on koala populations, therefore improving resilience overall.

Priorities for NPWS acquisition of koala areas are made based on resilience, reservation level and the extent to which the resilience of an area may be improved by the land use change (into conservation management).

Appendix E provides a quick reference to all ARKS, including the mapped resilience class, security and dominant threats (to be considered for SoS actions). Other useful statistics are also provided, including a records analysis of reservation, IBRA region and Koala Management Region.

Table 17 Setting priorities for SoS actions and land conservation (acquisition and conservation agreement)

Resilience class	Security	Relevant threats	Priority for action
Low	Low	Threats which can be mitigated at the site or area scale	**Low–moderate for site scale actions** (e.g. mitigation of dog and vehicle mortality) **Moderate for area scale actions** (e.g. refugia and connectivity projects)
Moderate or high	Moderate or high	Threats which can be mitigated at the site or area scale	**High for site and area scale actions** (e.g. SoS actions for vehicle strike, dog attack, habitat restoration and connectivity).
Moderate or high	Low	Threats which can be mitigated by land use change	High for acquisition priority and other conservation strategies (e.g. NPWS acquisition and BCT programs)

Interpreting the ARKS profiles

Introduction and overview

An ARKS profile has been assembled for each of the 48 Areas of Regional Koala Significance. The profile contains a map of the area complete with resilience class, security class, functional habitat classes, threat likelihood maps and a concise set of critical statistics.

Of the 48 ARKS recognised by this study in New South Wales, 13 have been ranked as high resilience, 22 as moderate resilience and 13 as low resilience. Figure 7 below displays the resilience rank for these areas across eastern New South Wales, while Figure 8 displays their security rank. Appendix C provides an alphabetical list of areas with their corresponding resilience rank while Appendix D lists them with their security rank.

There is a clear pattern of declining resilience in western New South Wales and parts of the north coast. This decline reflects the intensity of mapped threatening processes acting on koalas. For areas in western New South Wales, threats influenced by climatic factors (such as heat stress, fire and climate change) are strongest, while in coastal areas, the urban and development-related threats such as habitat loss, vehicle strike and dog attack have the most influence.

When assessed at a bioregional scale, the resilience trends are more apparent, with eight of the 13 low resilience areas in western bioregions and four of the remaining five in South Eastern Queensland Bioregion. High resilience areas are more evenly distributed, with the south east well represented (three areas) and most of the remainder in the NSW North Coast and Sydney Basin bioregions.

Table 18 lists the number of high, moderate and low resilience koala areas by bioregion.

Table 18 Resilience class of Areas of Regional Koala Significance by bioregion

Bioregion	High resilience	Moderate resilience	Low resilience	Total
Brigalow Belt South			4	4
Nandewar		1	1	2
New England Tablelands	1	1	1	3
NSW North Coast	6	12		18
NSW South Western Slopes			1	1
Riverina			1	1
South East Corner	2			2
South East Highlands	1		1	2
South Eastern Queensland		6	4	10
Sydney Basin	3	2		5
Total	13	22	13	48

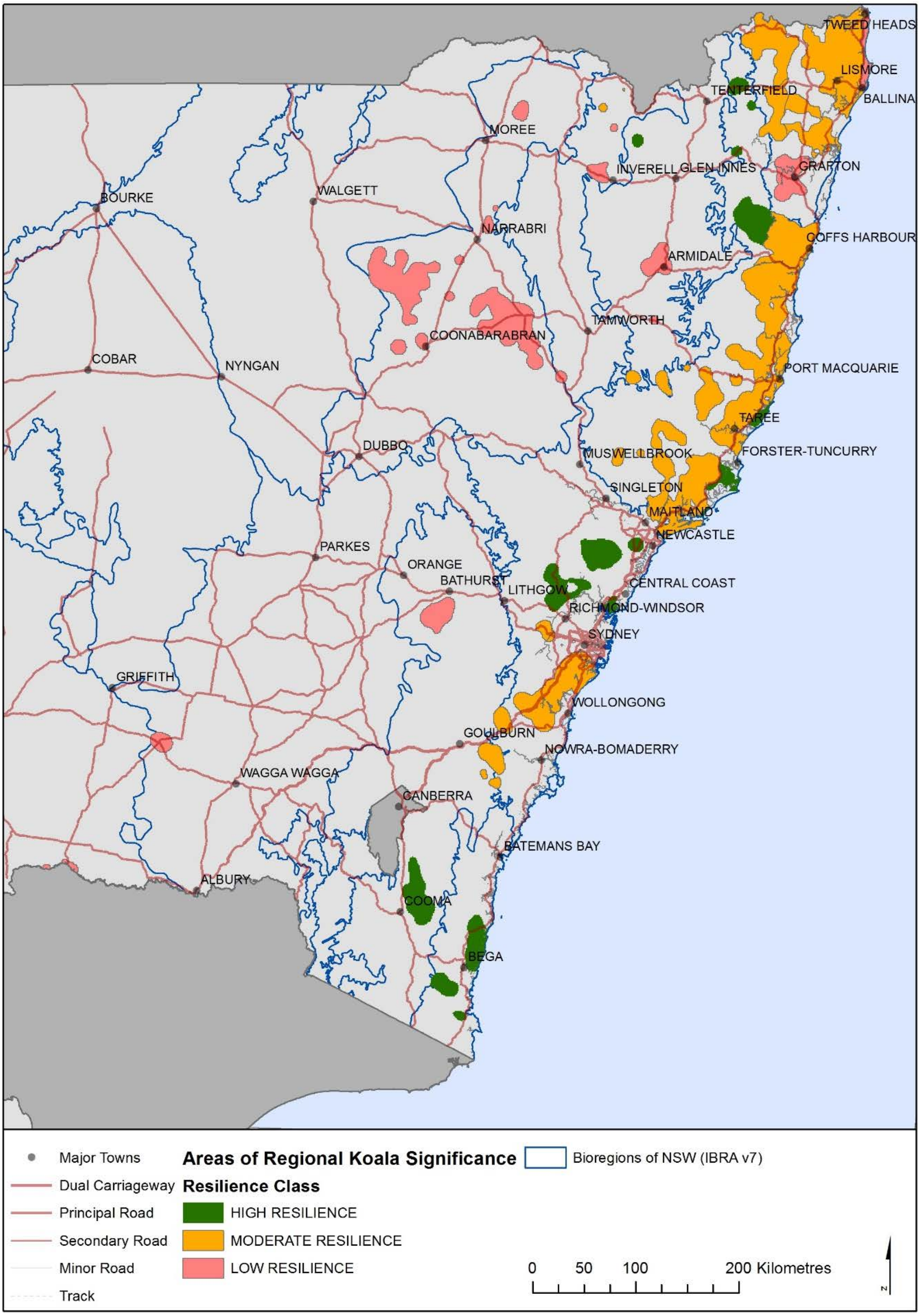


Figure 7 **Resilience of Areas of Regional Koala Significance for New South Wales**

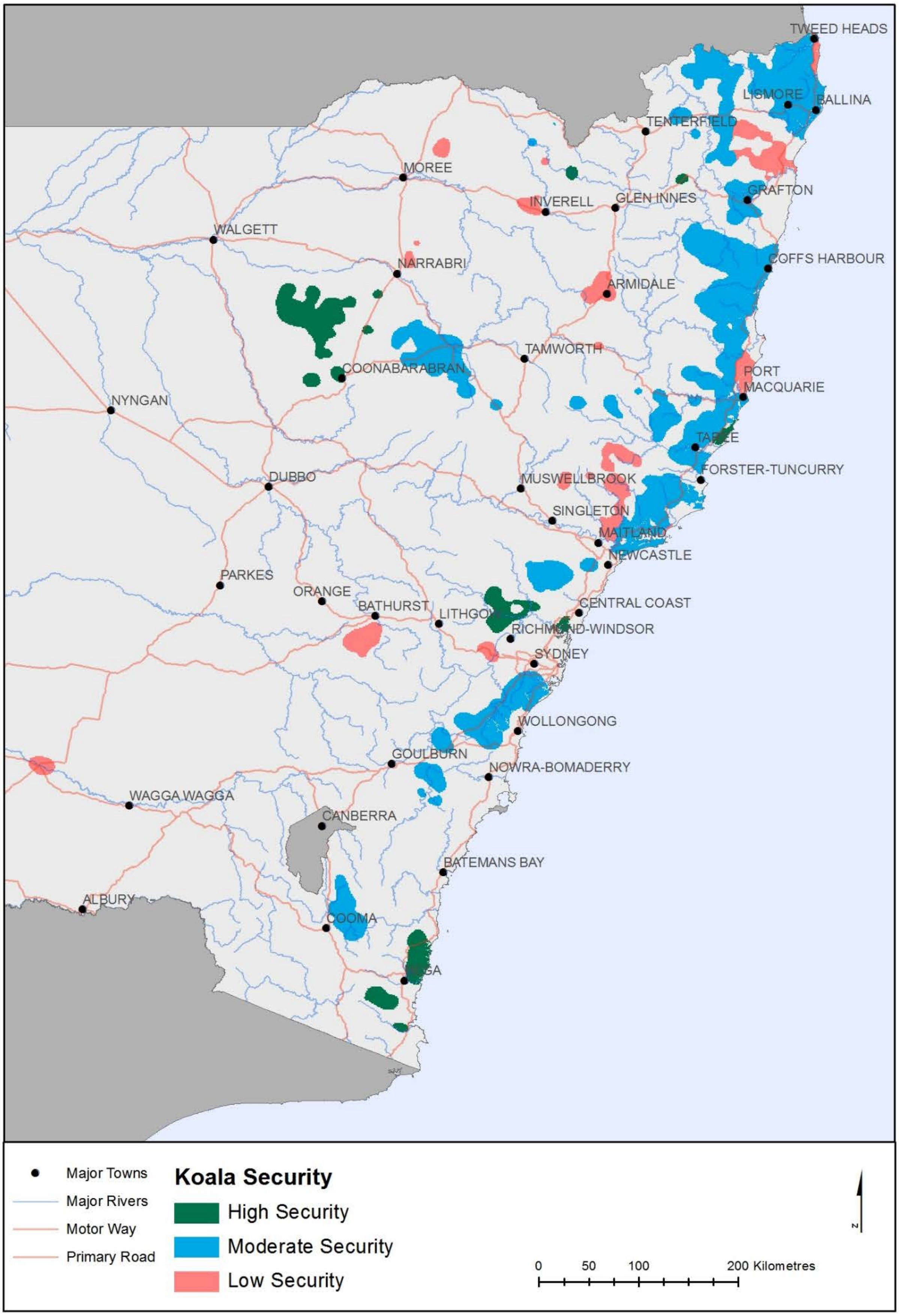


Figure 8 **Security of Areas of Regional Koala Significance for New South Wales**

The ARKS profile maps

Each ARKS profile map contained in Appendix A has been standardised to display a set of key indicators including resilience class, security class, sub-ARKS names (where there are more than one), area, IBRA region and threat risk class. This set of indicators has been brought together to provide all the critical information developed as part of this study for each koala area.

While most of the information provided by the profile is self-explanatory, some require additional interpretation.

Koala sub-areas

In the process of developing the ARKS, some disjunct areas recognised as significant by the analysis were subsequently grouped under a single regional name for the purposes of profiling. This process of grouping for analysis was undertaken manually and assisted by two key datasets:

existing koala population and meta-population boundaries (Scotts 2013, Paull & Hughes 2016, DECCW 2010a)

recognised barriers to koala movement (Scotts 2013).

Areas of disjunct koala significance within an ARKS have been referred to as sub-areas and are recognised and explicitly defined on each profile map.

Overall threat risk (scaled)

To assist with the prioritisation of SoS actions (*Assigning priority actions* in Step 6), a generalised threat risk rank has been assigned to each threat category for each ARKS. The risk ranking for each threat category has been assigned based on the relative prevalence and level of risk across each area.

An average index of risk for each threat category was developed, then ranked across all areas from highest to lowest. Using the full range of average risk, four range quartiles were defined and used to assign the risk categories as shown in Table 19. Using this method, the risk ranks are relative in nature, meaning that a risk rank of 'Very high' is assigned to the top 25% of the range of ARKS for vehicle strike, even if the risk shows high likelihood over less than 50% of the area.

It is important to note also, that the threat maps in the profiles show likelihood of a threat event, not risk, as the risk to each koala value varies with the nominated consequence (Table 8). Therefore, some variance can be expected between the risk rank and the mapped likelihood categories, especially with threat categories with a very high consequence (such as fire) or low consequence (such as disease).

Figure 9 below displays an example map with key information identified.

Table 19 Threat risk rank categories for Areas of Regional Koala Significance

Area risk rank	Criteria	Description
Very high	Top 25% of risk range	The threat category has an overwhelming influence on koala persistence in the area.
High	Top 50% of risk range	The threat category has a marked influence on koala persistence in the area.
Moderate	Lower 50% of risk range	The influence of the threat category in the area is noticeable, but not prevalent in the area.

Low	Lower 25% of risk range	The threat category is absent, or insignificant in the area.

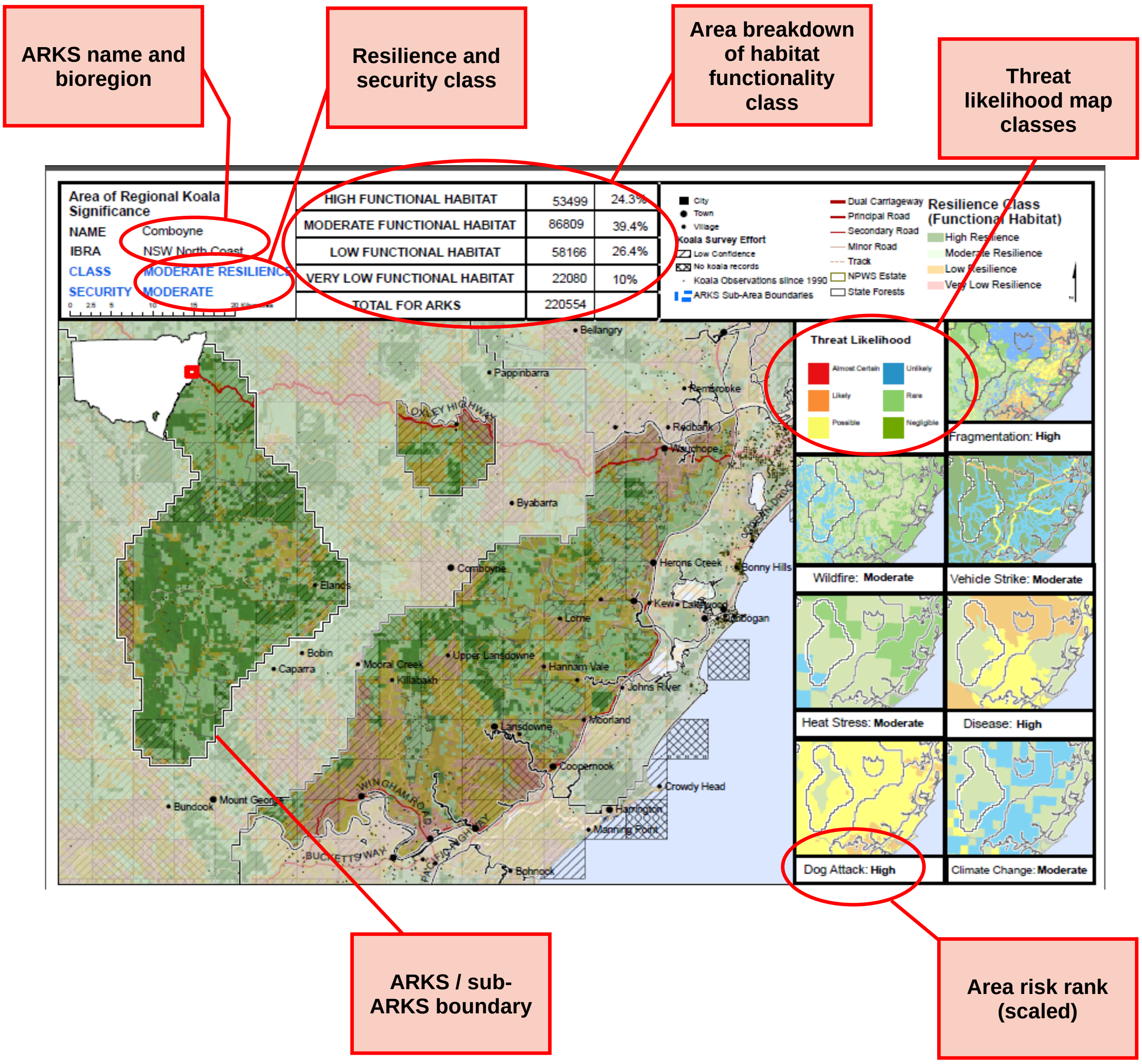


Figure 9 **Resilience profile example for interpretation**

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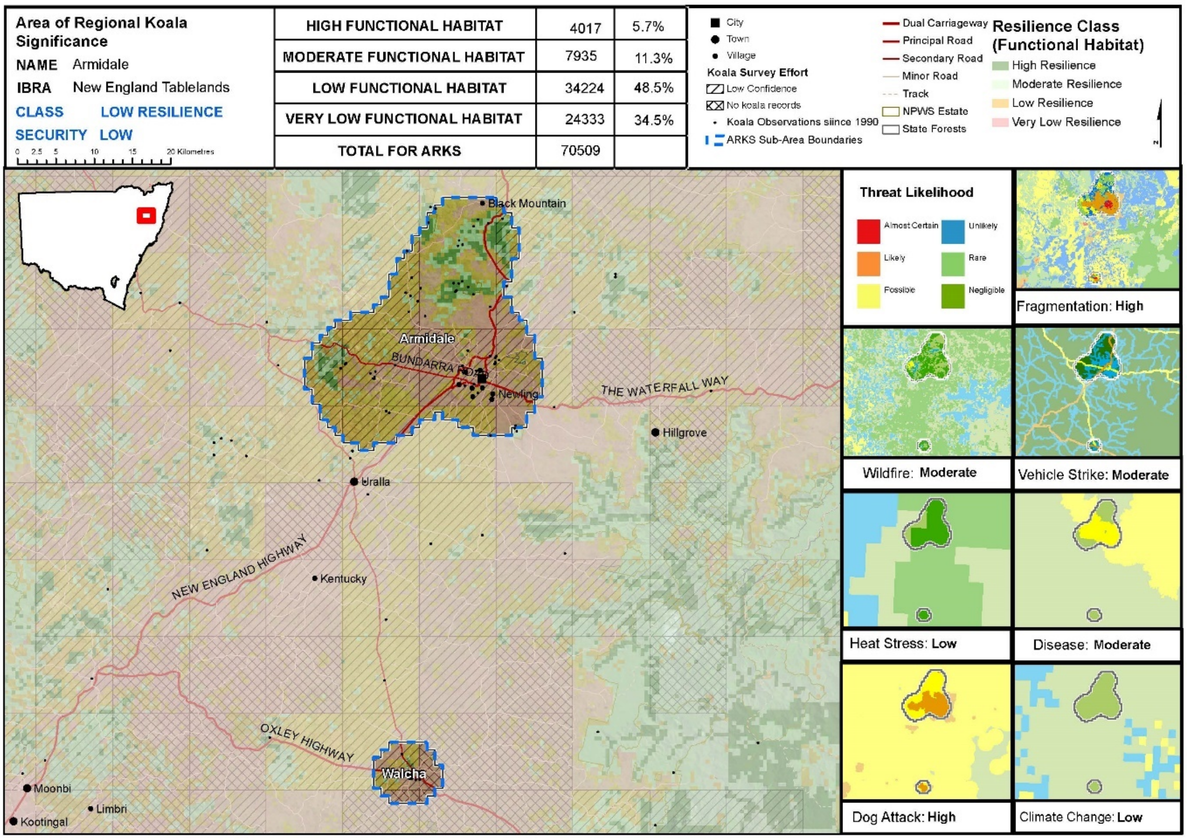
Appendix A Areas of Regional Koala Significance – profiles

A detailed profile is provided for each of the 48 Area of Regional Koala Significance (ARKS), including resilience class, security class, sub-ARKS name, area, IBRA region and threat risk class.

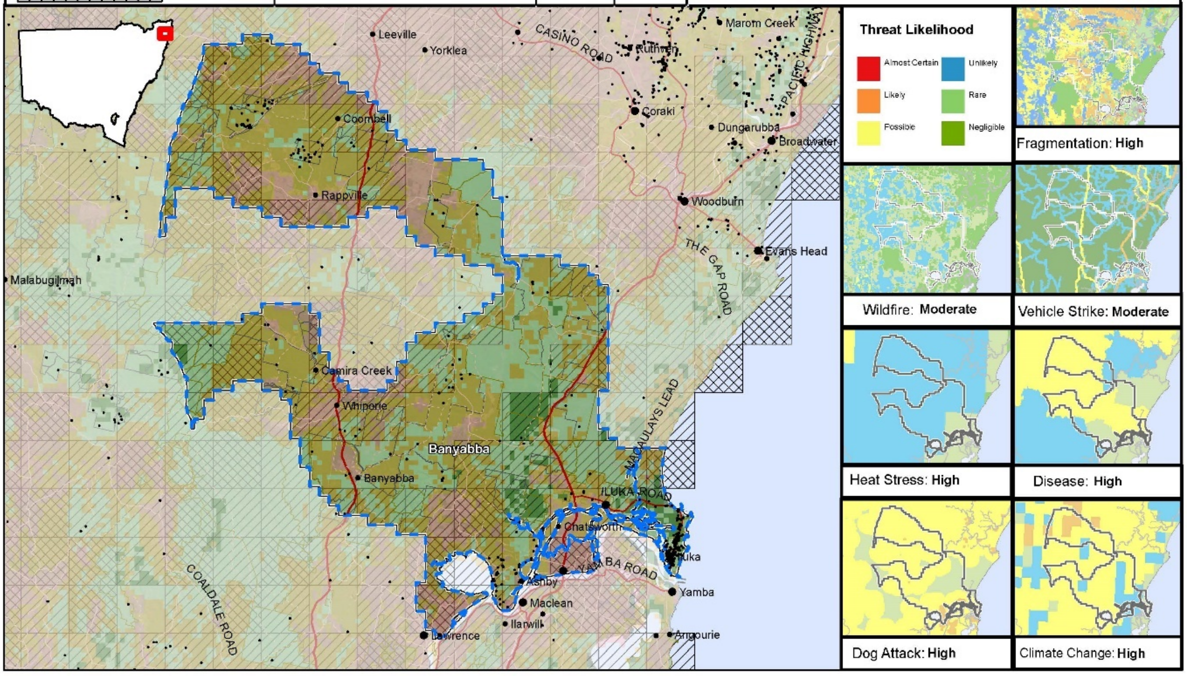


Map 1 **Area of Regional Koala Significance Profile Map Armidale**

Area of Regional Koala Significance			
NAME Banyabba	HIGH FUNCTIONAL HABITAT	6627	4.7%
IBRA South Eastern Queensland	MODERATE FUNCTIONAL HABITAT	54519	38.5%
CLASS MODERATE RESILIENCE	LOW FUNCTIONAL HABITAT	60156	42.4%
SECURITY LOW	VERY LOW FUNCTIONAL HABITAT	20472	14.4%
	TOTAL FOR ARKS	141774	

City; Town; Village; Koala Survey Effort; Low Confidence; No koala records; Koala Observations siince 1990; ARKS Sub-Area Boundaries; Dual Carriageway; Principal Road; Secondary Road; Minor Road; Track; NPWS Estate; State Forests

Resilience Class (Functional Habitat): High Resilience; Moderate Resilience; Low Resilience; Very Low Resilience

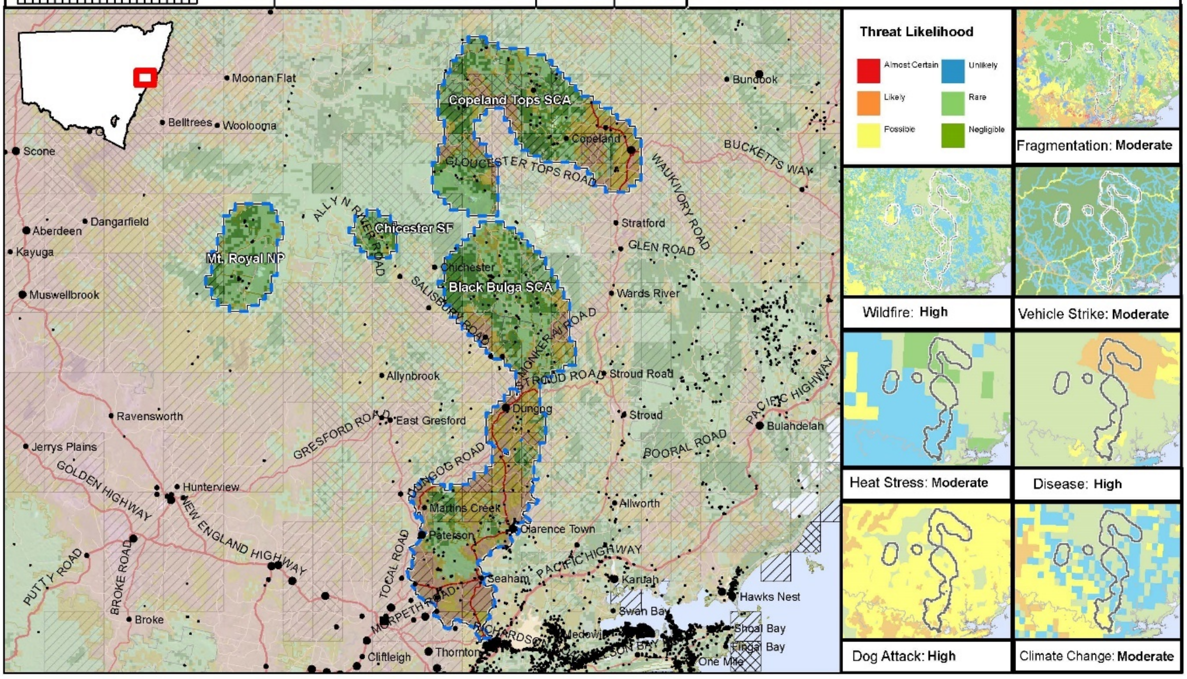


Map 2 **Area of Regional Koala Significance Profile Map Banyabba**

Area of Regional Koala Significance			
NAME Barrington	HIGH FUNCTIONAL HABITAT	41394	24.8%
IBRA NSW North Coast	MODERATE FUNCTIONAL HABITAT	60129	36.1%
CLASS MODERATE RESILIENCE	LOW FUNCTIONAL HABITAT	39095	23.5%
SECURITY LOW	VERY LOW FUNCTIONAL HABITAT	26042	15.6%
	TOTAL FOR ARKS	166660	

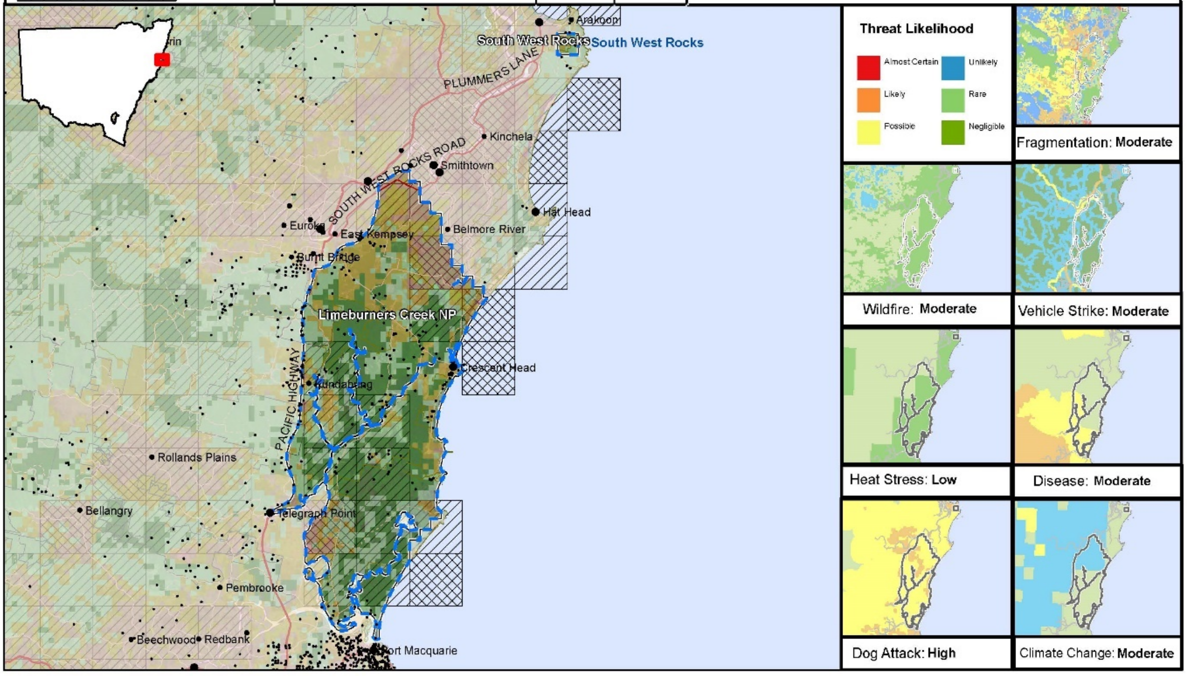
City; Town; Village; Koala Survey Effort; Low Confidence; No koala records; Koala Observations siince 1990; ARKS Sub-Area Boundaries; Dual Carriageway; Principal Road; Secondary Road; Minor Road; Track; NPWS Estate; State Forests

Resilience Class (Functional Habitat): High Resilience; Moderate Resilience; Low Resilience; Very Low Resilience



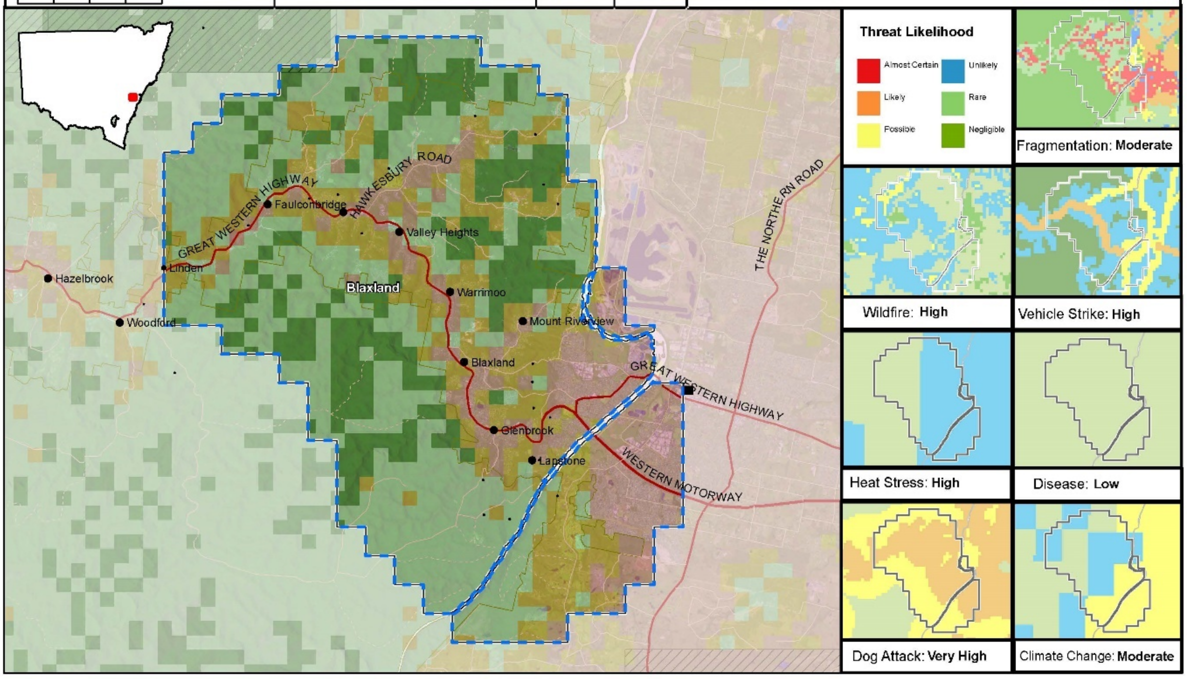
Map 3 **Area of Regional Koala Significance Profile Map Barrington**

Area of Regional Koala Significance	HIGH FUNCTIONAL HABITAT	19788	41.2%
NAME Belmore River	MODERATE FUNCTIONAL HABITAT	13069	27.2%
IBRA NSW North Coast	LOW FUNCTIONAL HABITAT	10845	22.6%
CLASS MODERATE RESILIENCE	VERY LOW FUNCTIONAL HABITAT	4325	9%
SECURITY LOW	TOTAL FOR ARKS	48027	

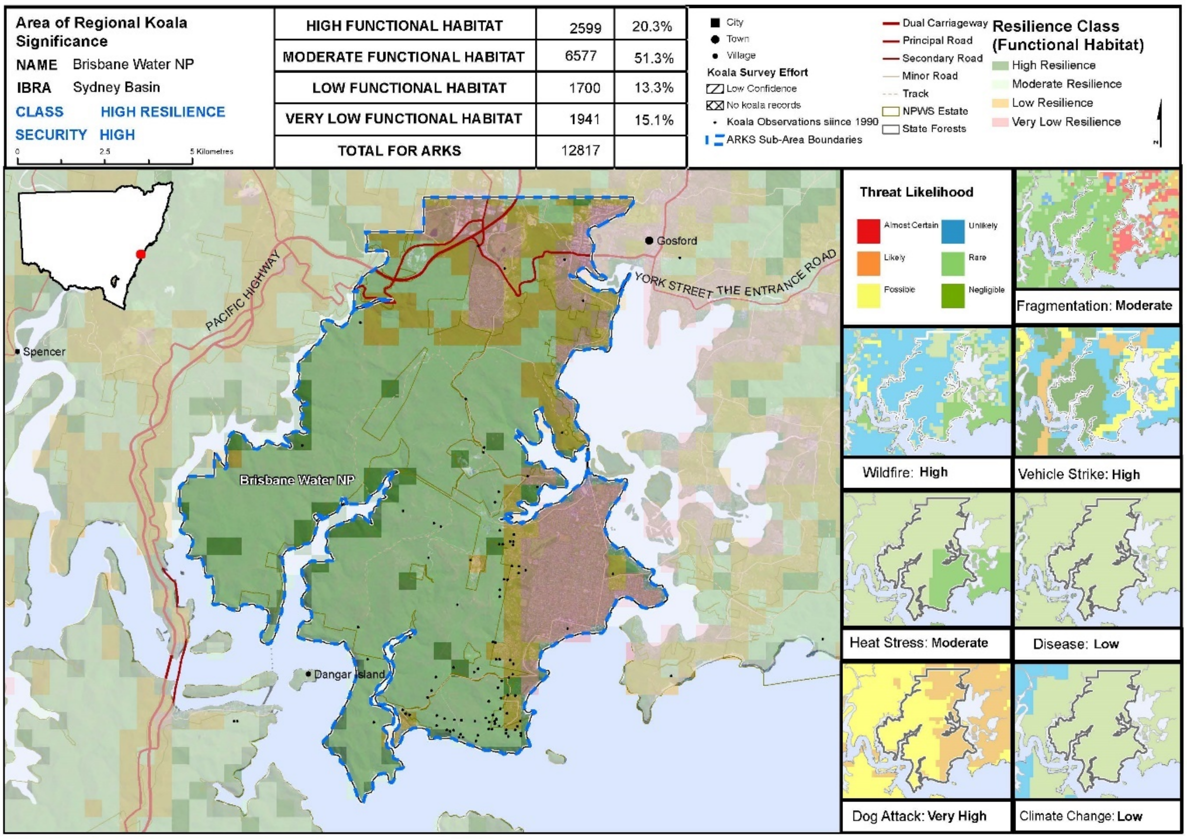


Map 4 **Area of Regional Koala Significance Profile Map Belmore River**

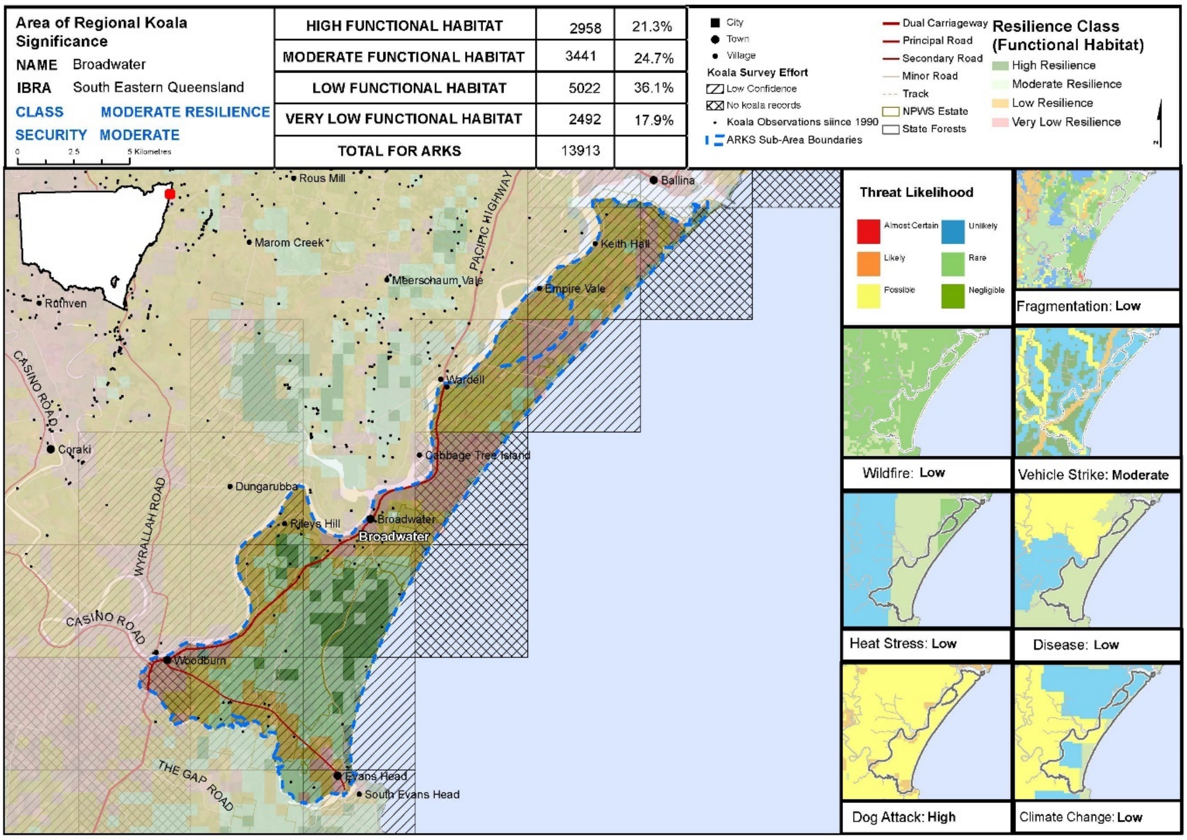
Area of Regional Koala Significance	HIGH FUNCTIONAL HABITAT	3685	14.9%
NAME Blaxland	MODERATE FUNCTIONAL HABITAT	11404	46%
IBRA Sydney Basin	LOW FUNCTIONAL HABITAT	5479	22.1%
CLASS MODERATE RESILIENCE	VERY LOW FUNCTIONAL HABITAT	4232	17.1%
SECURITY LOW	TOTAL FOR ARKS	24800	



Map 5 **Area of Regional Koala Significance Profile Map Blaxland**



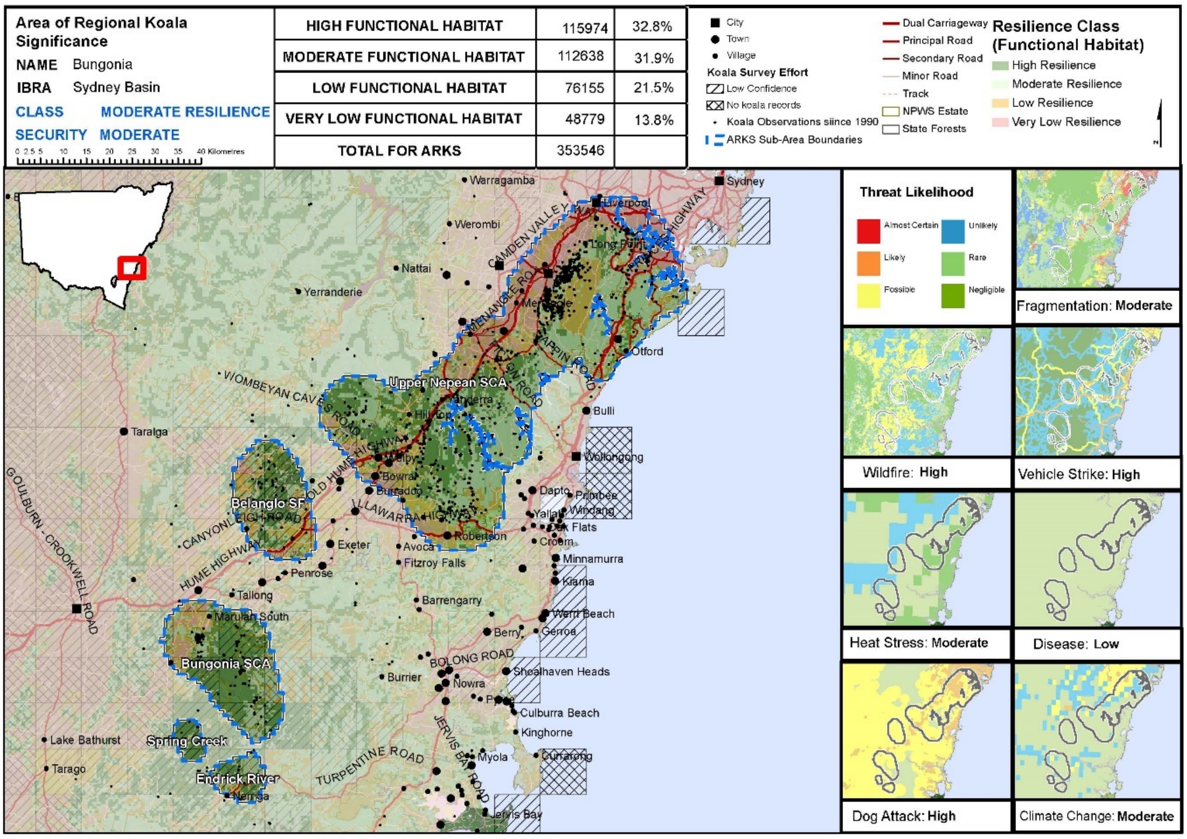
Map 6 **Area of Regional Koala Significance Profile Map Brisbane Water National Park**



Map 7 **Area of Regional Koala Significance Profile Map Broadwater**

Area of Regional Koala Significance
NAME Bungonia
IBRA Sydney Basin
CLASS MODERATE RESILIENCE
SECURITY MODERATE

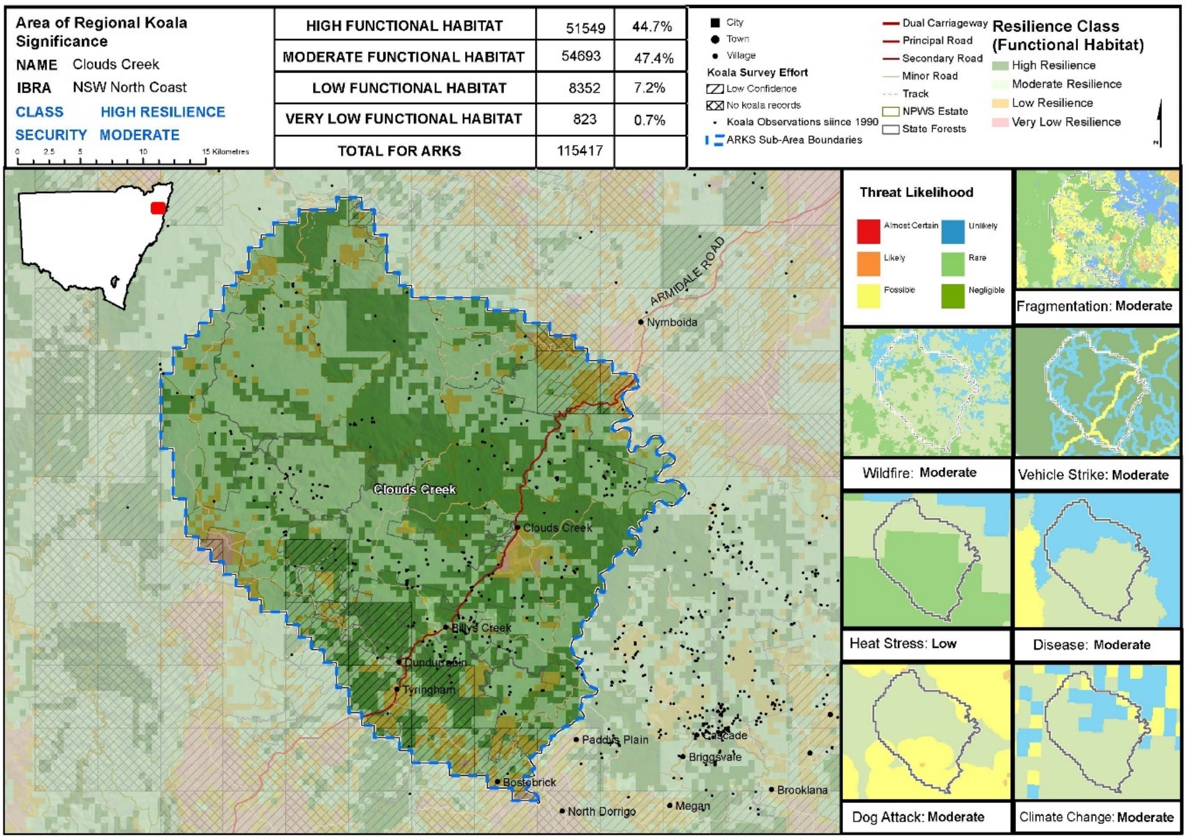
HIGH FUNCTIONAL HABITAT	115974	32.8%
MODERATE FUNCTIONAL HABITAT	112638	31.9%
LOW FUNCTIONAL HABITAT	76155	21.5%
VERY LOW FUNCTIONAL HABITAT	48779	13.8%
TOTAL FOR ARKS	353546	



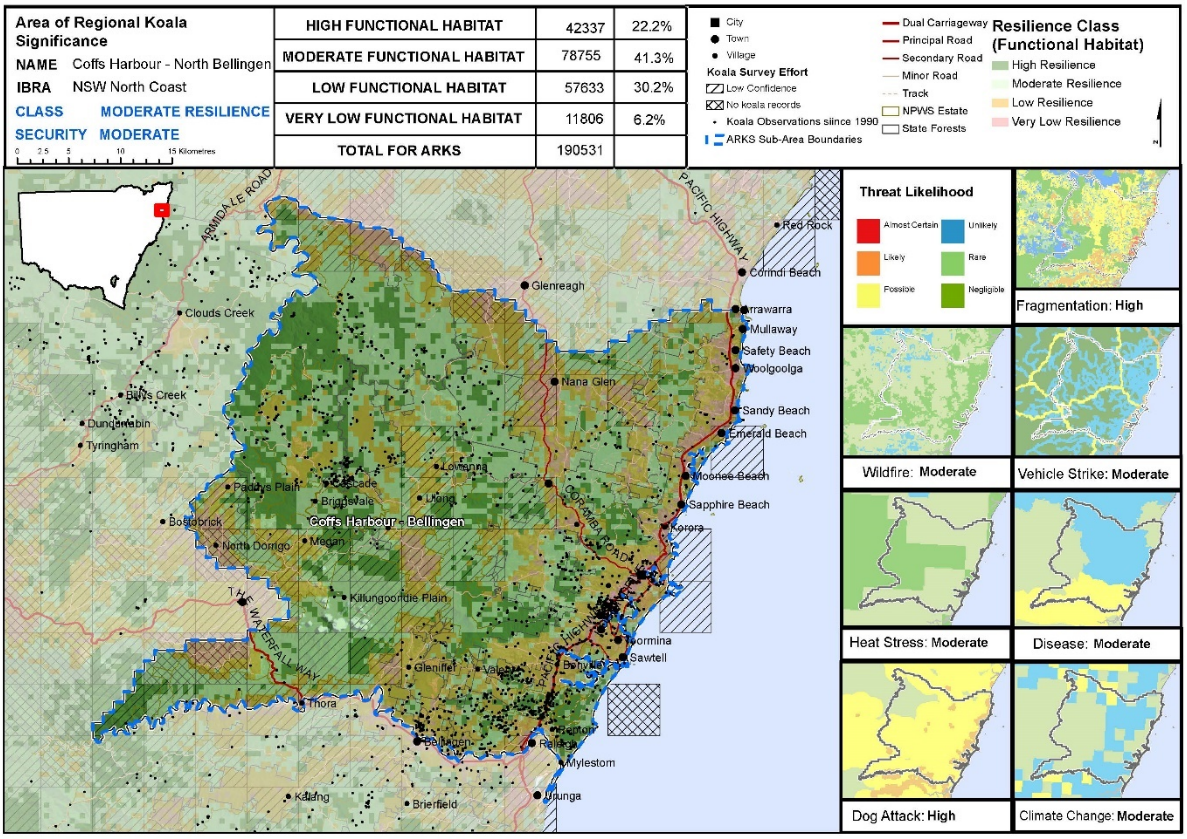
Map 8 **Area of Regional Koala Significance Profile Map Bungonia**

Area of Regional Koala Significance
NAME Clouds Creek
IBRA NSW North Coast
CLASS HIGH RESILIENCE
SECURITY MODERATE

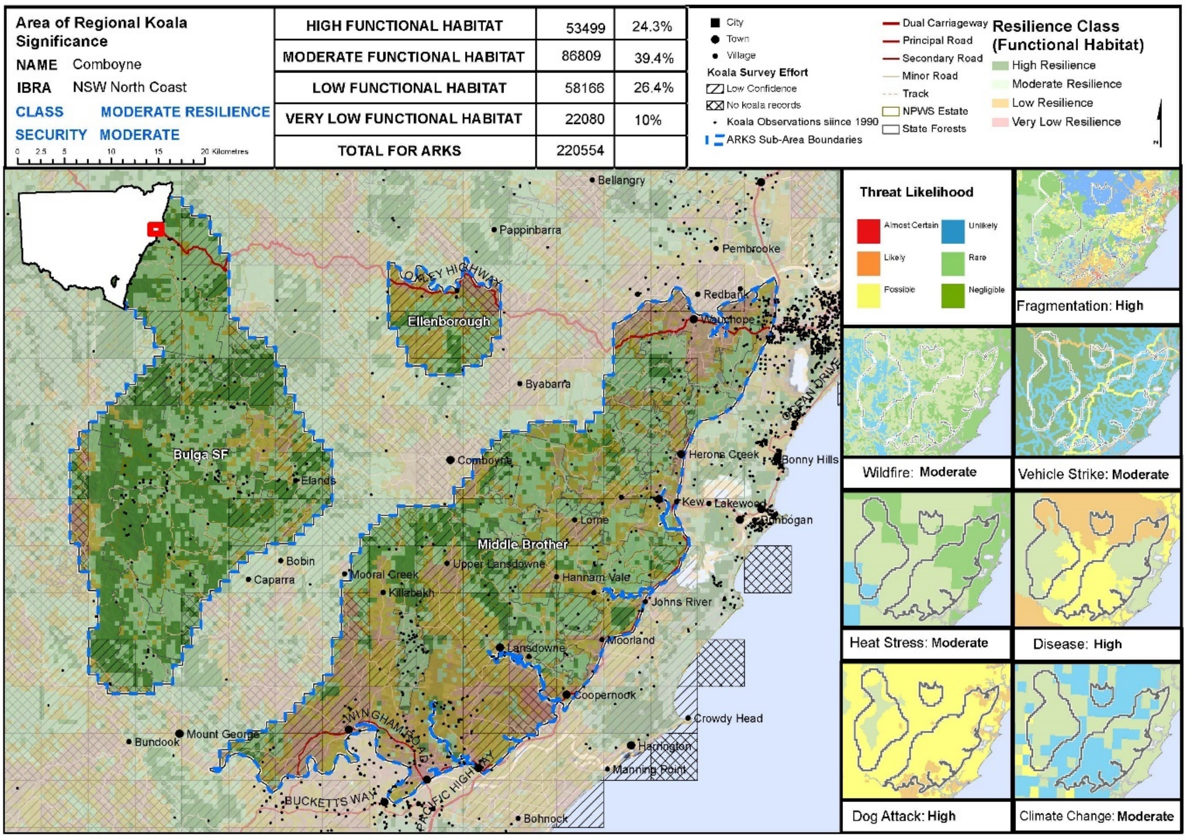
HIGH FUNCTIONAL HABITAT	51549	44.7%
MODERATE FUNCTIONAL HABITAT	54693	47.4%
LOW FUNCTIONAL HABITAT	8352	7.2%
VERY LOW FUNCTIONAL HABITAT	823	0.7%
TOTAL FOR ARKS	115417	



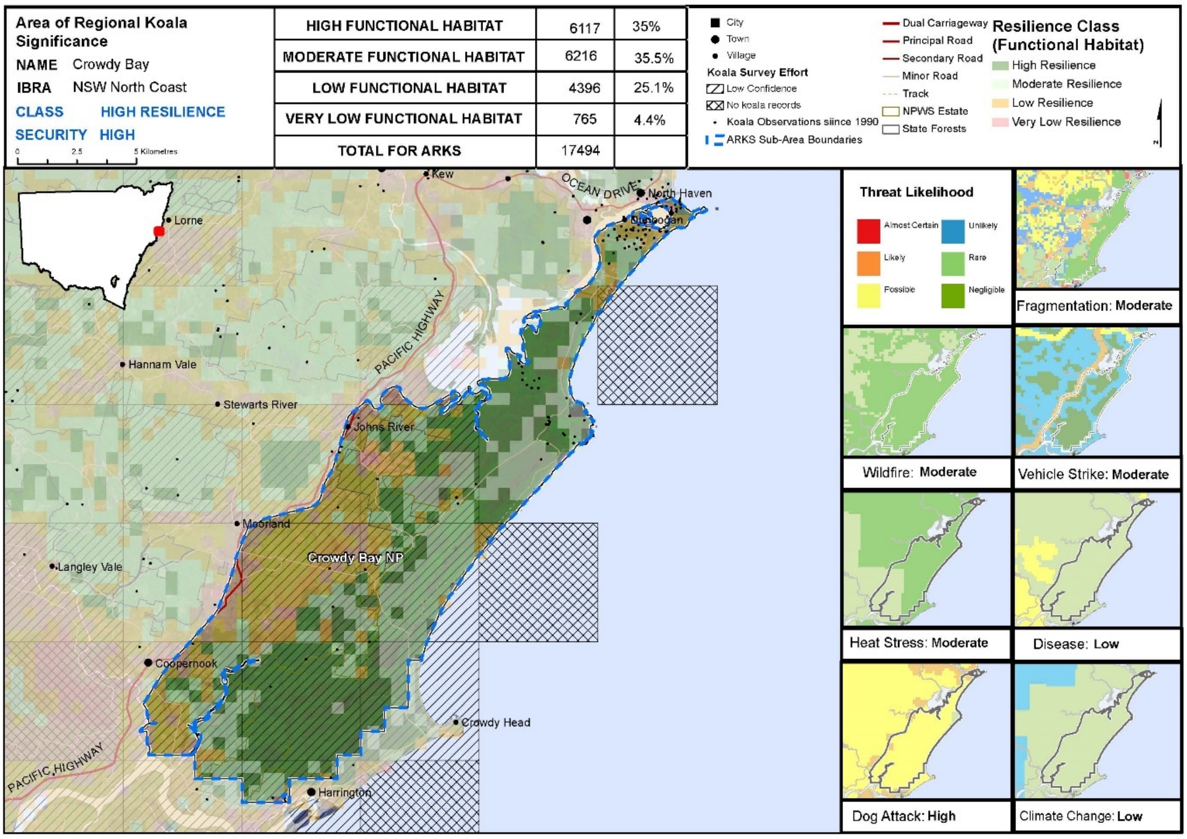
Map 9 **Area of Regional Koala Significance Profile Map Clouds Creek**



Map 10 **Area of Regional Koala Significance Profile Map Coffs Harbour – North Bellingen**

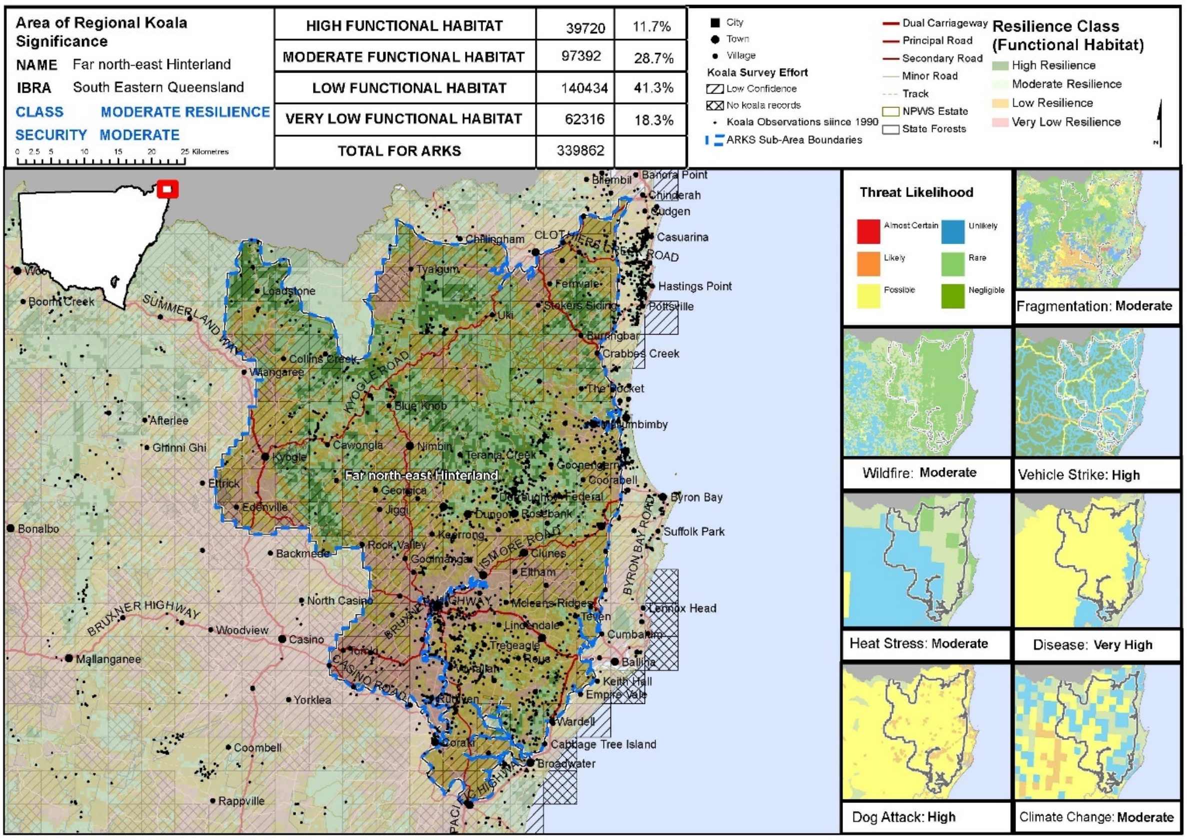


Map 11 **Area of Regional Koala Significance Profile Map Comboyne**



HIGH FUNCTIONAL HABITAT	6117	35%
MODERATE FUNCTIONAL HABITAT	6216	35.5%
LOW FUNCTIONAL HABITAT	4396	25.1%
VERY LOW FUNCTIONAL HABITAT	765	4.4%
TOTAL FOR ARKS	17494	

Map 12 Area of Regional Koala Significance Profile Map Crowdy Bay

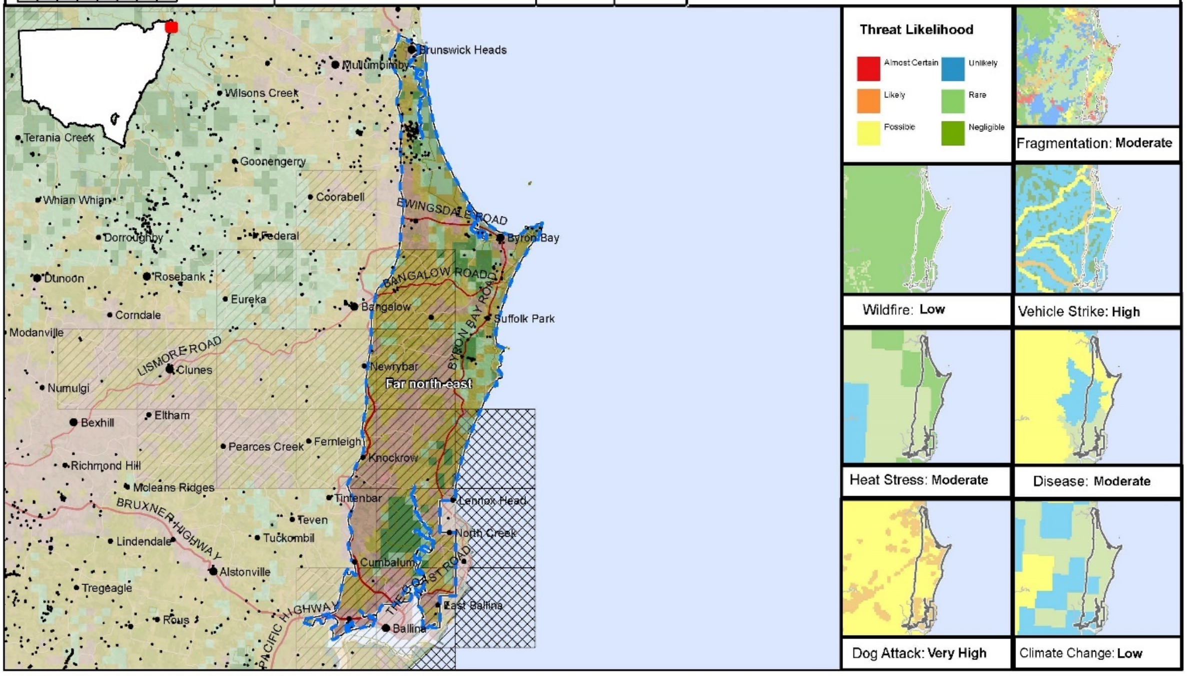


HIGH FUNCTIONAL HABITAT	39720	11.7%
MODERATE FUNCTIONAL HABITAT	97392	28.7%
LOW FUNCTIONAL HABITAT	140434	41.3%
VERY LOW FUNCTIONAL HABITAT	62316	18.3%
TOTAL FOR ARKS	339862	

Map 13 Area of Regional Koala Significance Profile Map Far north-east Hinterland

Area of Regional Koala Significance
NAME Far north-east
IBRA South Eastern Queensland
CLASS LOW RESILIENCE
SECURITY MODERATE

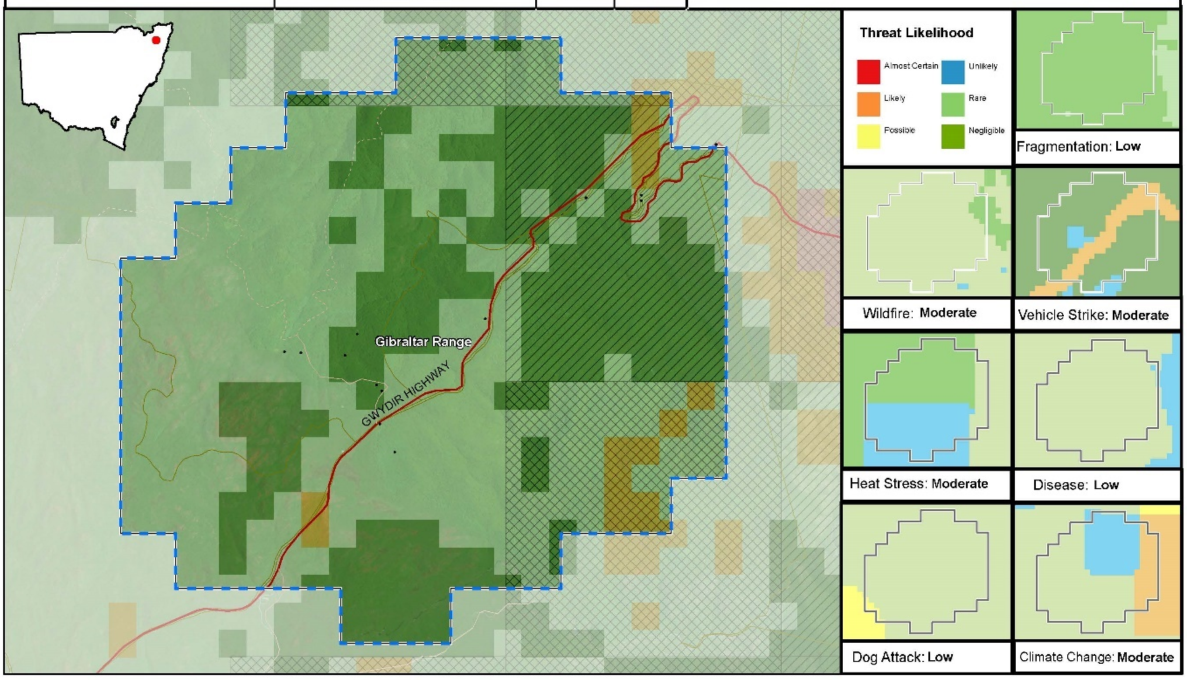
HIGH FUNCTIONAL HABITAT	1830	8.8%
MODERATE FUNCTIONAL HABITAT	4008	19.2%
LOW FUNCTIONAL HABITAT	9492	45.6%
VERY LOW FUNCTIONAL HABITAT	5497	26.4%
TOTAL FOR ARKS	20827	



Map 14 **Area of Regional Koala Significance Profile Map Far north-east**

Area of Regional Koala Significance
NAME Gibraltar Range
IBRA NSW North Coast
CLASS HIGH RESILIENCE
SECURITY HIGH

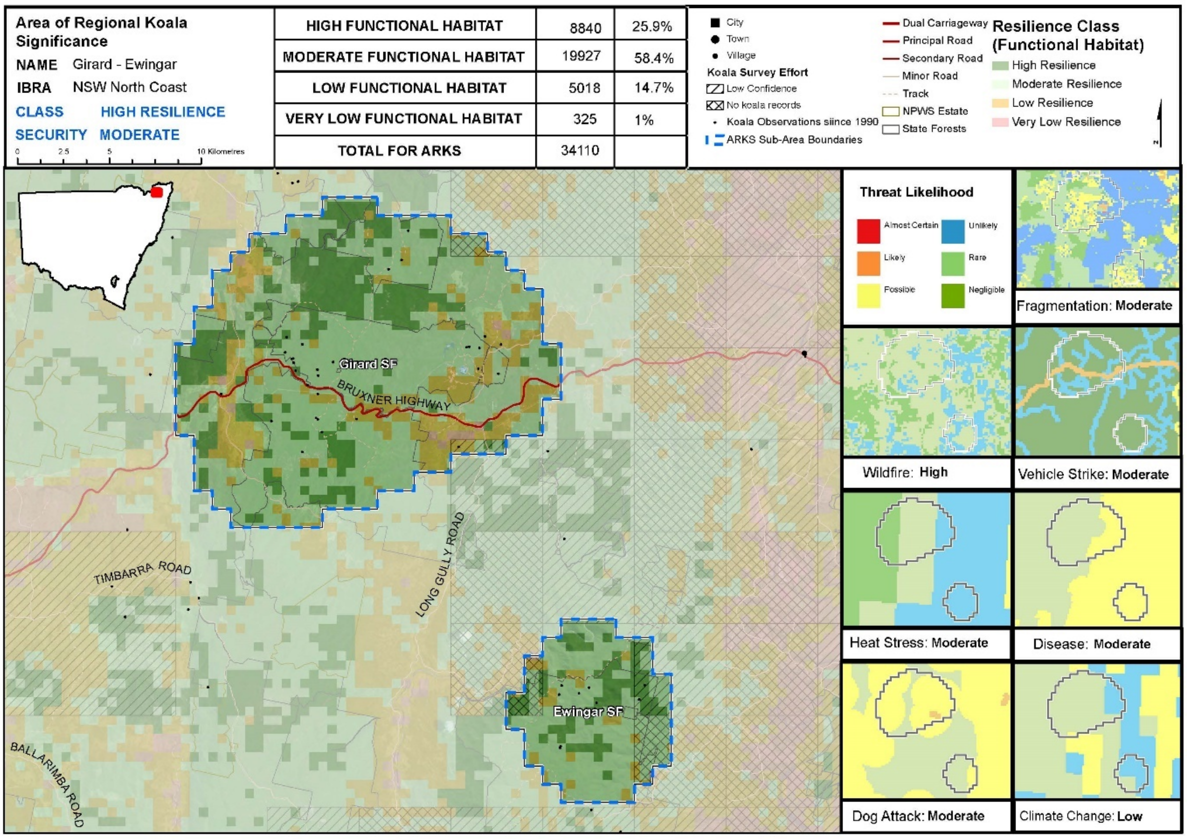
HIGH FUNCTIONAL HABITAT	4774	51.9%
MODERATE FUNCTIONAL HABITAT	4432	48.1%
LOW FUNCTIONAL HABITAT	0	0%
VERY LOW FUNCTIONAL HABITAT	0	0%
TOTAL FOR ARKS	9206	



Map 15 **Area of Regional Koala Significance Profile Map Gibraltar Range**

Area of Regional Koala Significance
NAME Girard - Ewingar
IBRA NSW North Coast
CLASS HIGH RESILIENCE
SECURITY MODERATE

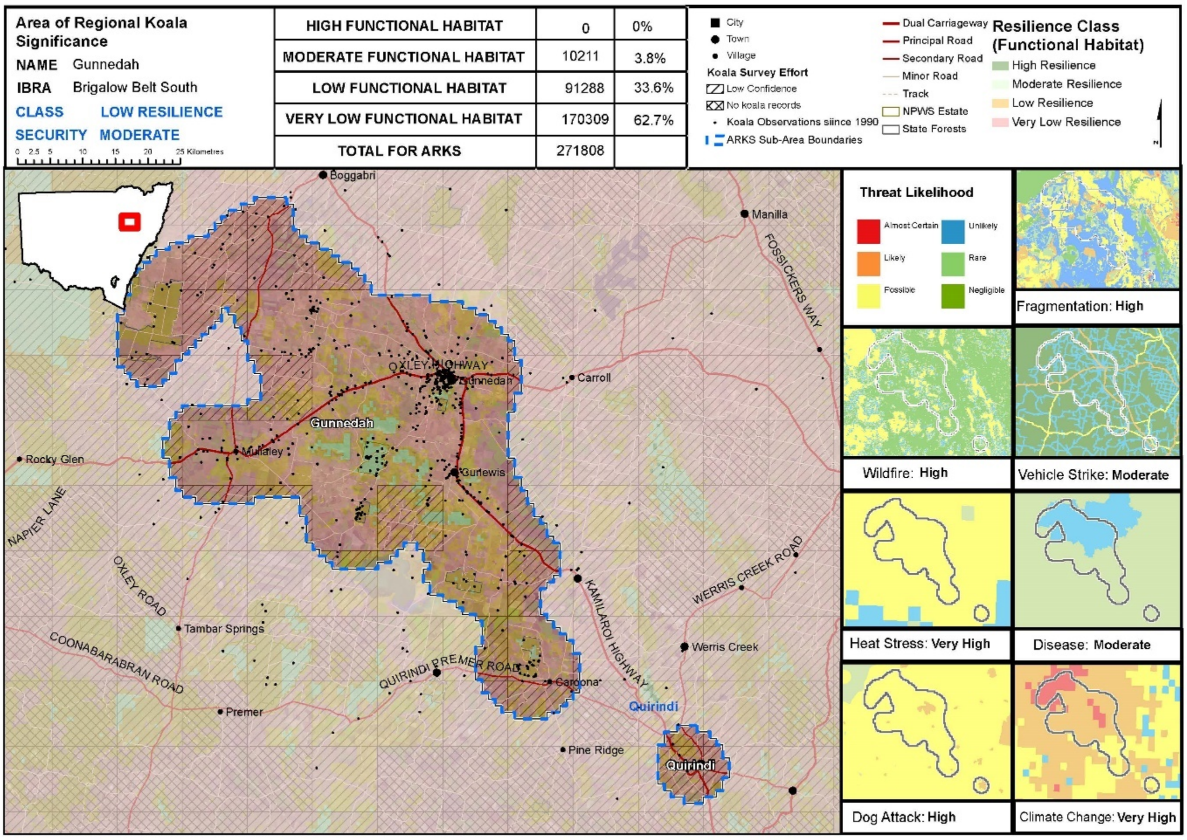
HIGH FUNCTIONAL HABITAT	8840	25.9%
MODERATE FUNCTIONAL HABITAT	19927	58.4%
LOW FUNCTIONAL HABITAT	5018	14.7%
VERY LOW FUNCTIONAL HABITAT	325	1%
TOTAL FOR ARKS	34110	



Map 16 Area of Regional Koala Significance Profile Map Girard – Ewingar

Area of Regional Koala Significance
NAME Gunnedah
IBRA Brigalow Belt South
CLASS LOW RESILIENCE
SECURITY MODERATE

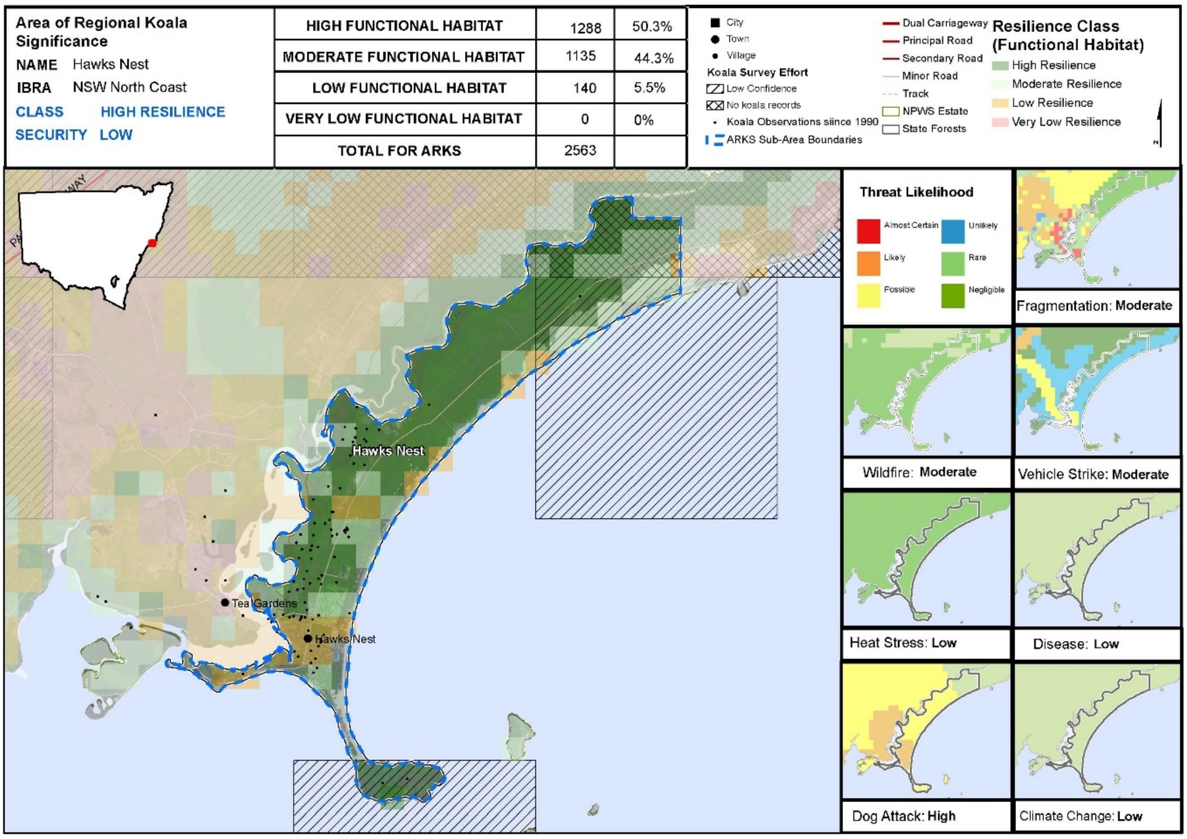
HIGH FUNCTIONAL HABITAT	0	0%
MODERATE FUNCTIONAL HABITAT	10211	3.8%
LOW FUNCTIONAL HABITAT	91288	33.6%
VERY LOW FUNCTIONAL HABITAT	170309	62.7%
TOTAL FOR ARKS	271808	



Map 17 Area of Regional Koala Significance Profile Map Gunnedah

Area of Regional Koala Significance
NAME Hawks Nest
IBRA NSW North Coast
CLASS HIGH RESILIENCE
SECURITY LOW

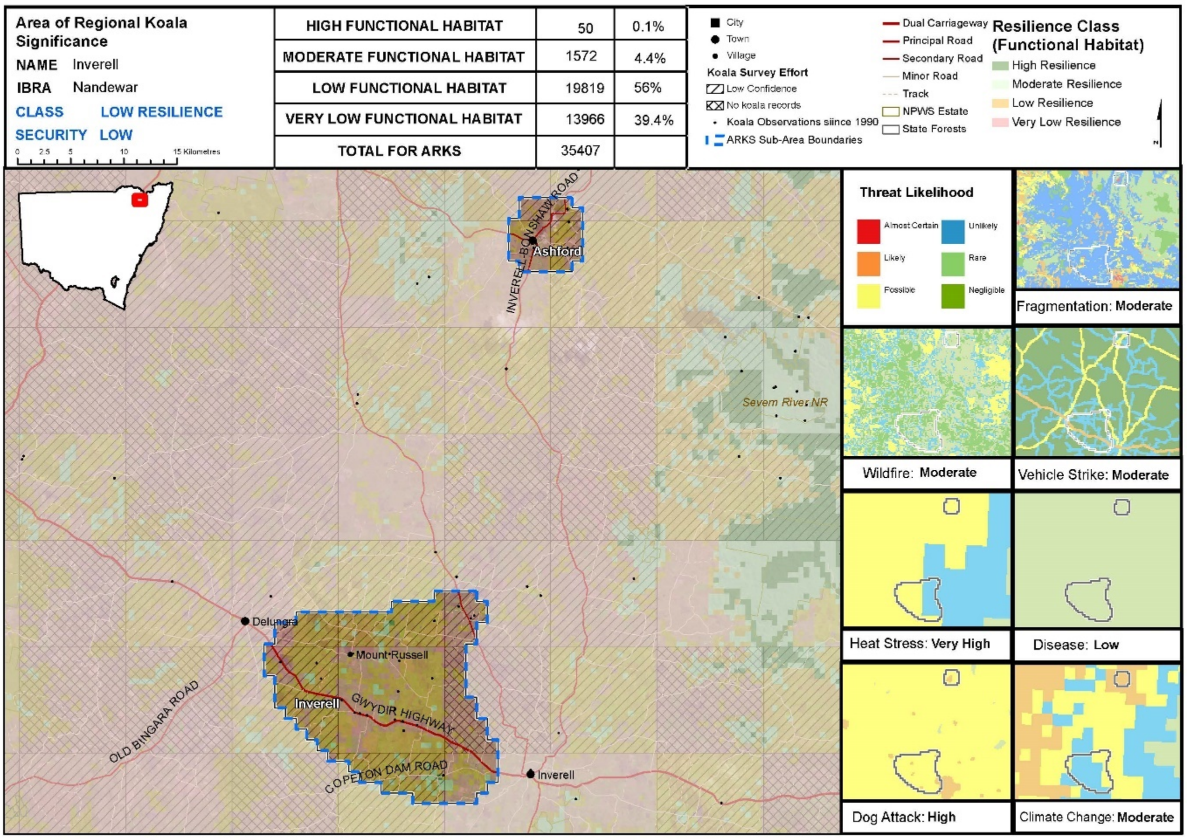
HIGH FUNCTIONAL HABITAT	1288	50.3%
MODERATE FUNCTIONAL HABITAT	1135	44.3%
LOW FUNCTIONAL HABITAT	140	5.5%
VERY LOW FUNCTIONAL HABITAT	0	0%
TOTAL FOR ARKS	2563	



Map 18 **Area of Regional Koala Significance Profile Map Hawks Nest**

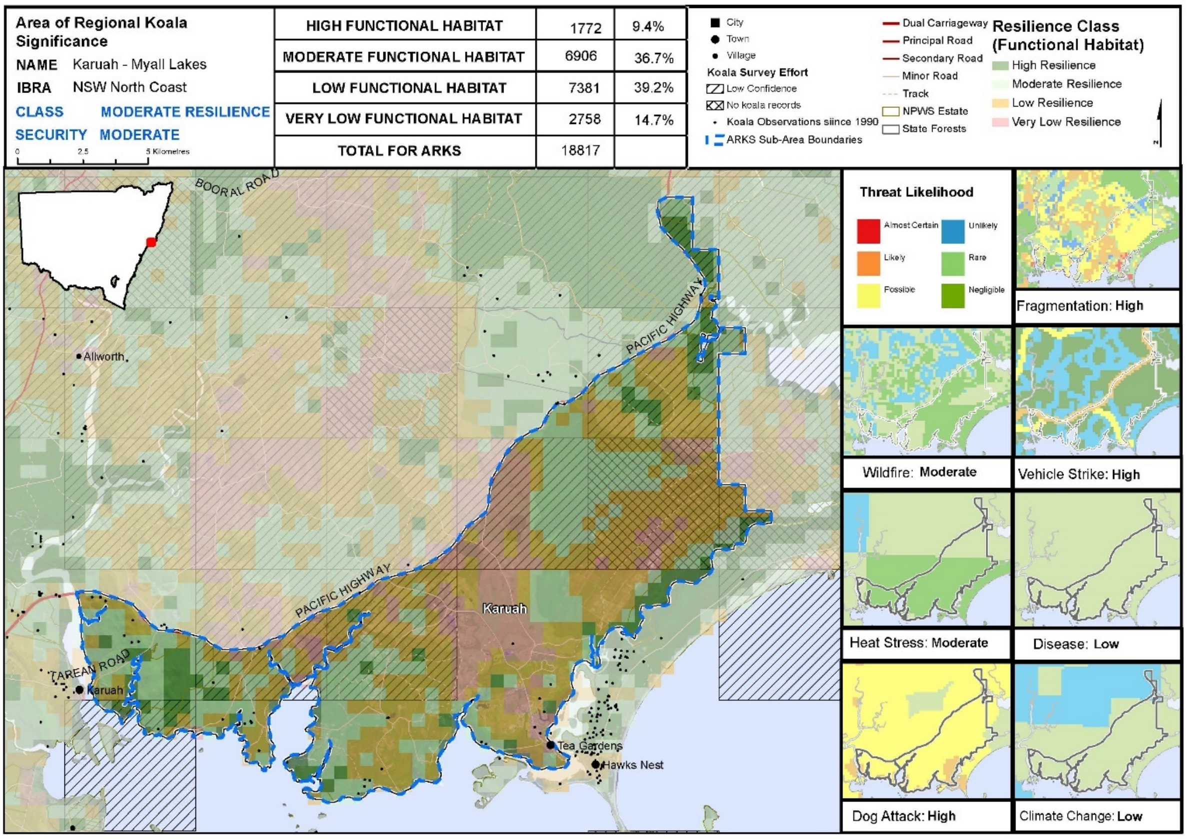
Area of Regional Koala Significance
NAME Inverell
IBRA Nandewar
CLASS LOW RESILIENCE
SECURITY LOW

HIGH FUNCTIONAL HABITAT	50	0.1%
MODERATE FUNCTIONAL HABITAT	1572	4.4%
LOW FUNCTIONAL HABITAT	19819	56%
VERY LOW FUNCTIONAL HABITAT	13966	39.4%
TOTAL FOR ARKS	35407	



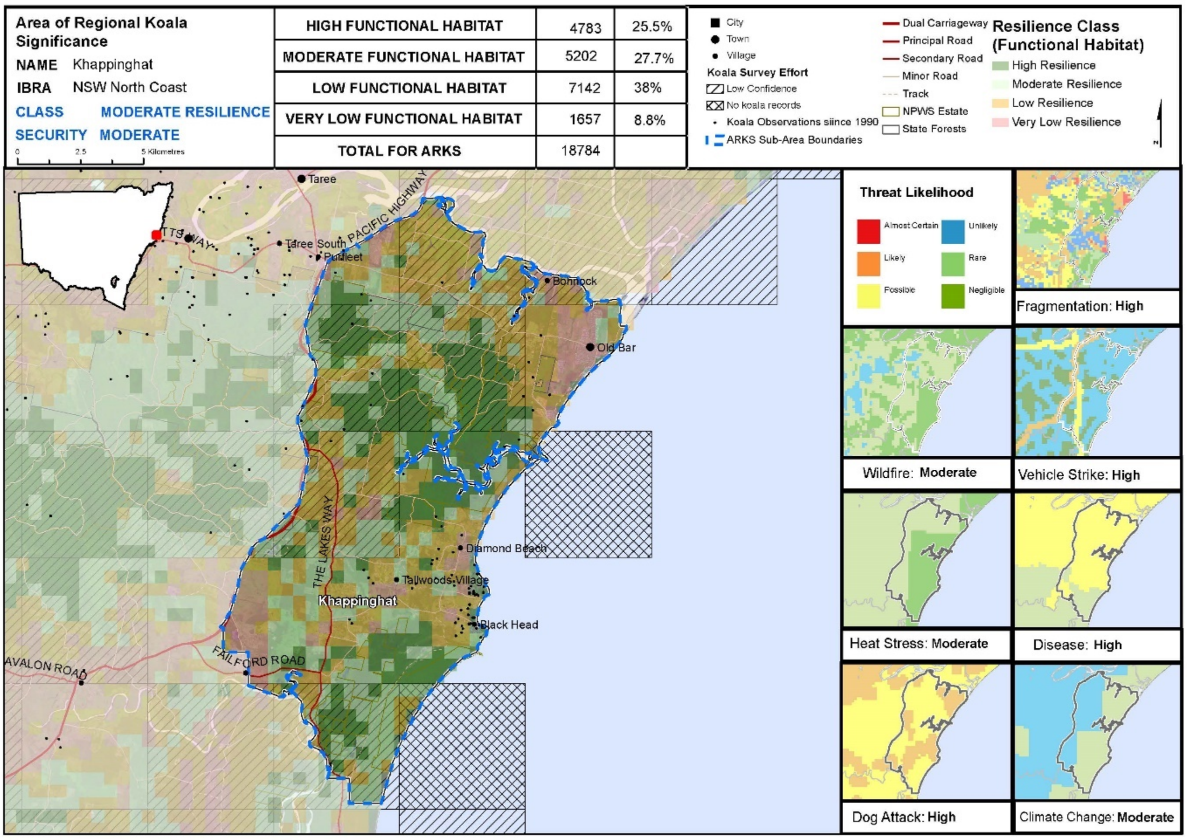
Map 19 **Area of Regional Koala Significance Profile Map Inverell**

Area of Regional Koala Significance			
NAME Karuah - Myall Lakes	HIGH FUNCTIONAL HABITAT	1772	9.4%
IBRA NSW North Coast	MODERATE FUNCTIONAL HABITAT	6906	36.7%
CLASS MODERATE RESILIENCE	LOW FUNCTIONAL HABITAT	7381	39.2%
SECURITY MODERATE	VERY LOW FUNCTIONAL HABITAT	2758	14.7%
	TOTAL FOR ARKS	18817	

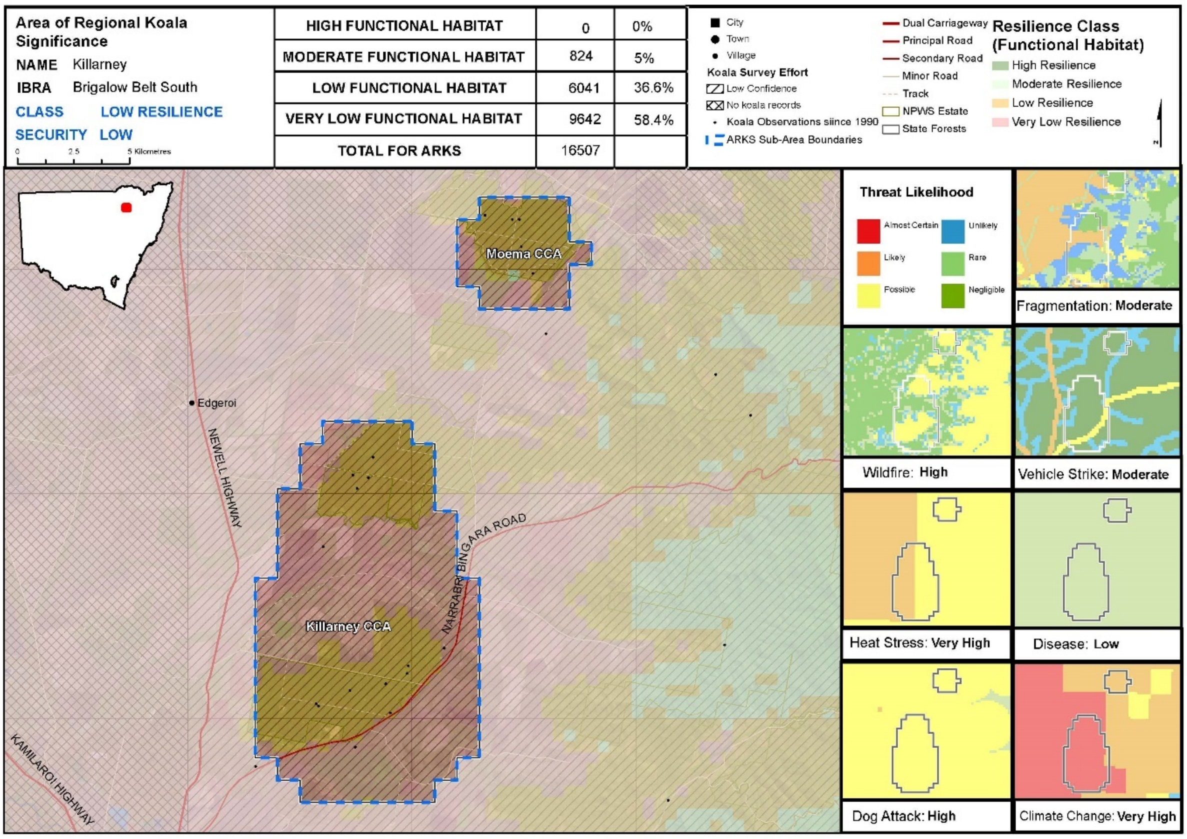


Map 20 Area of Regional Koala Significance Profile Map Karuah – Myall Lakes

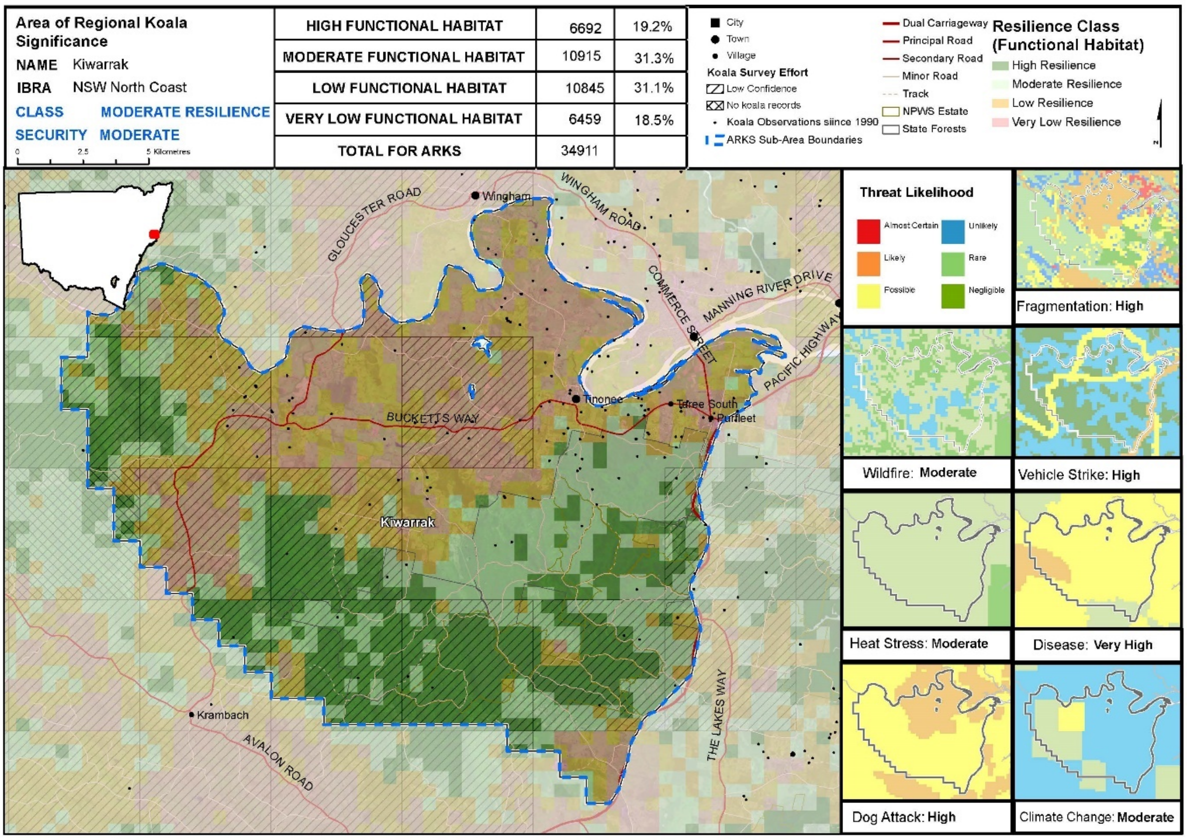
Area of Regional Koala Significance			
NAME Khappinghat	HIGH FUNCTIONAL HABITAT	4783	25.5%
IBRA NSW North Coast	MODERATE FUNCTIONAL HABITAT	5202	27.7%
CLASS MODERATE RESILIENCE	LOW FUNCTIONAL HABITAT	7142	38%
SECURITY MODERATE	VERY LOW FUNCTIONAL HABITAT	1657	8.8%
	TOTAL FOR ARKS	18784	



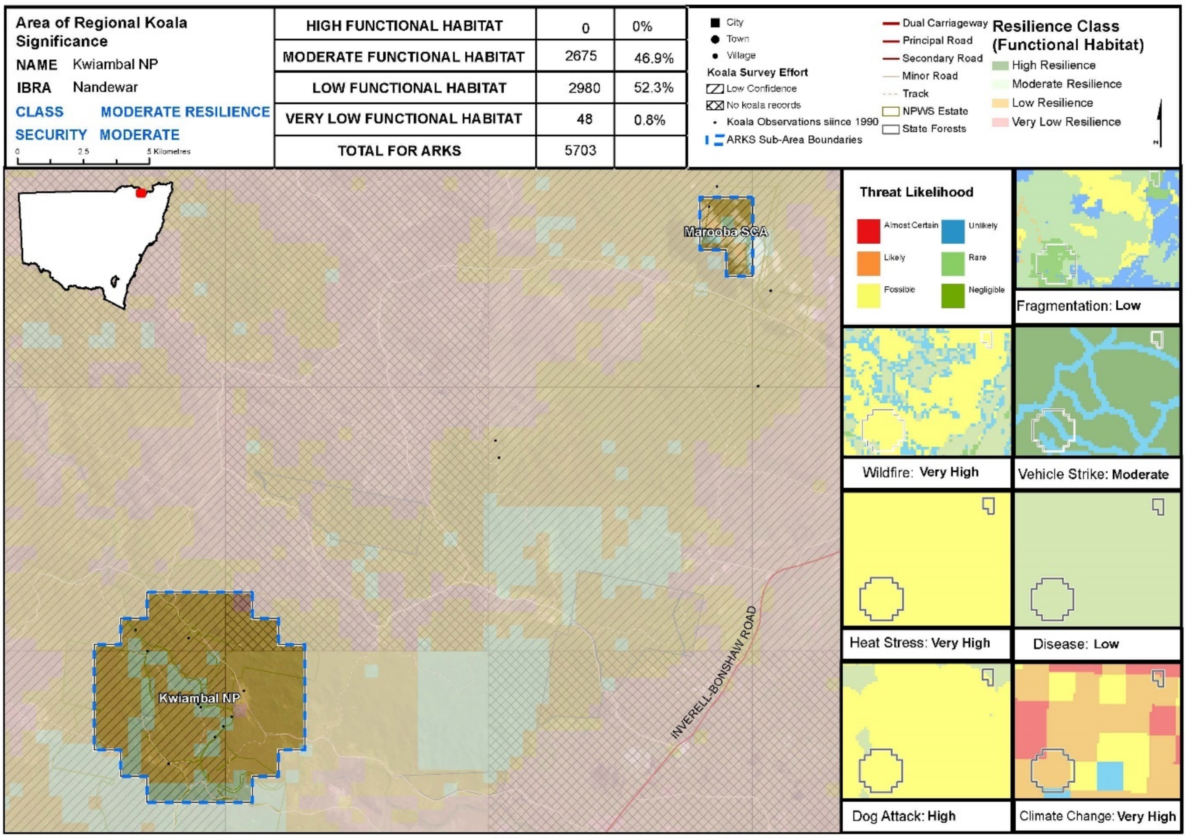
Map 21 Area of Regional Koala Significance Profile Map Khappinghat



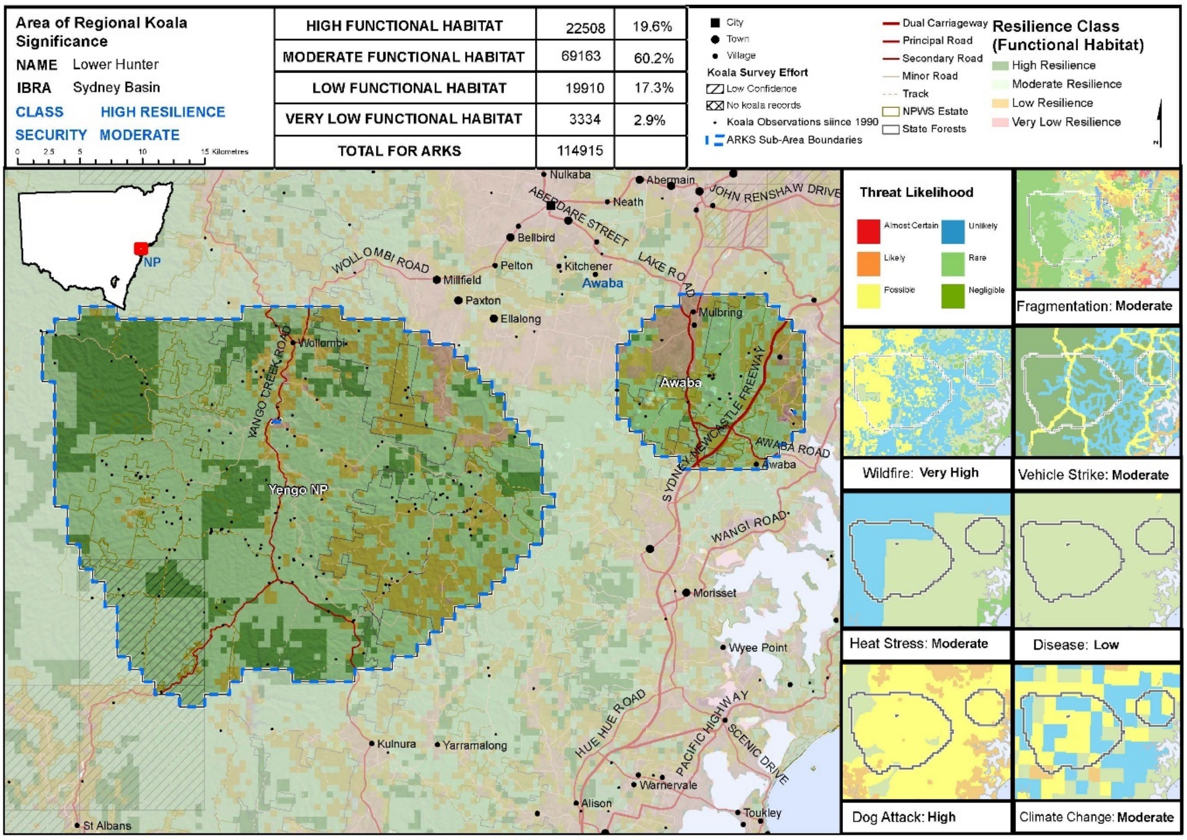
Map 22 **Area of Regional Koala Significance Profile Map Killarney**



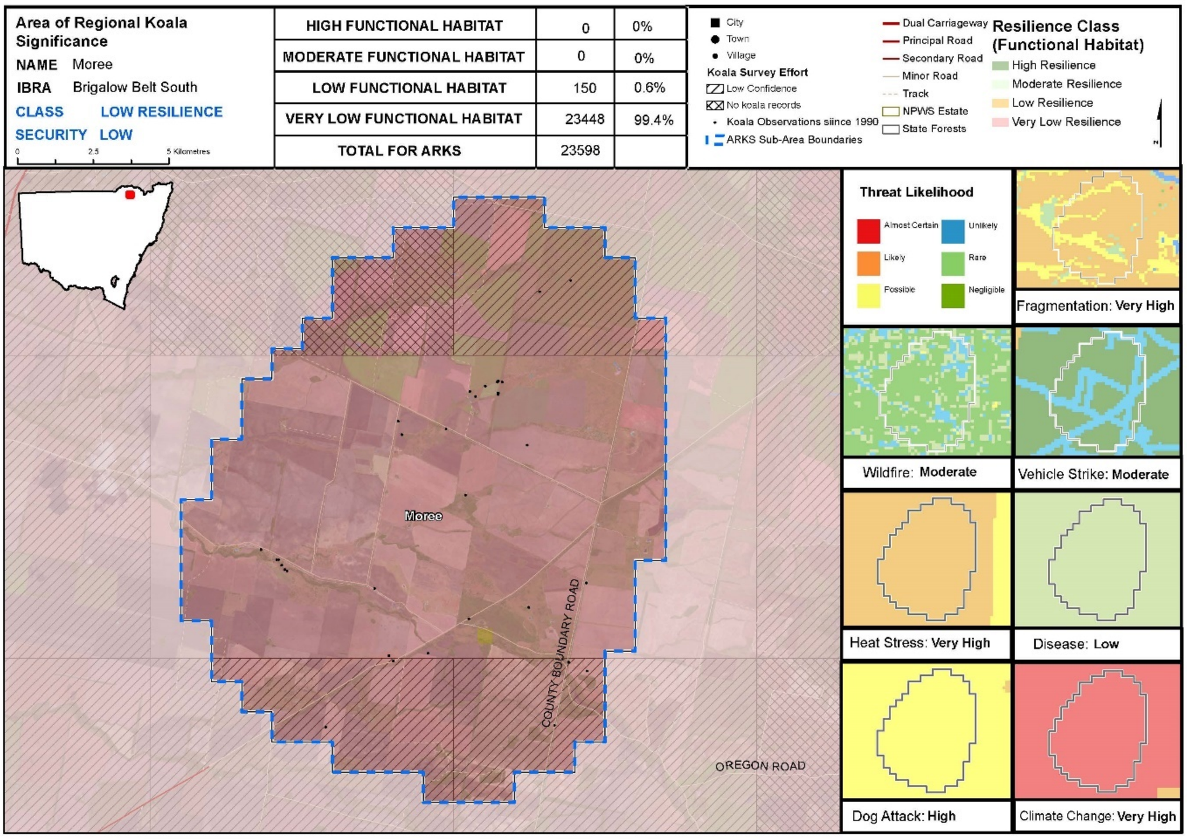
Map 23 **Area of Regional Koala Significance Profile Map Kiwarrak**



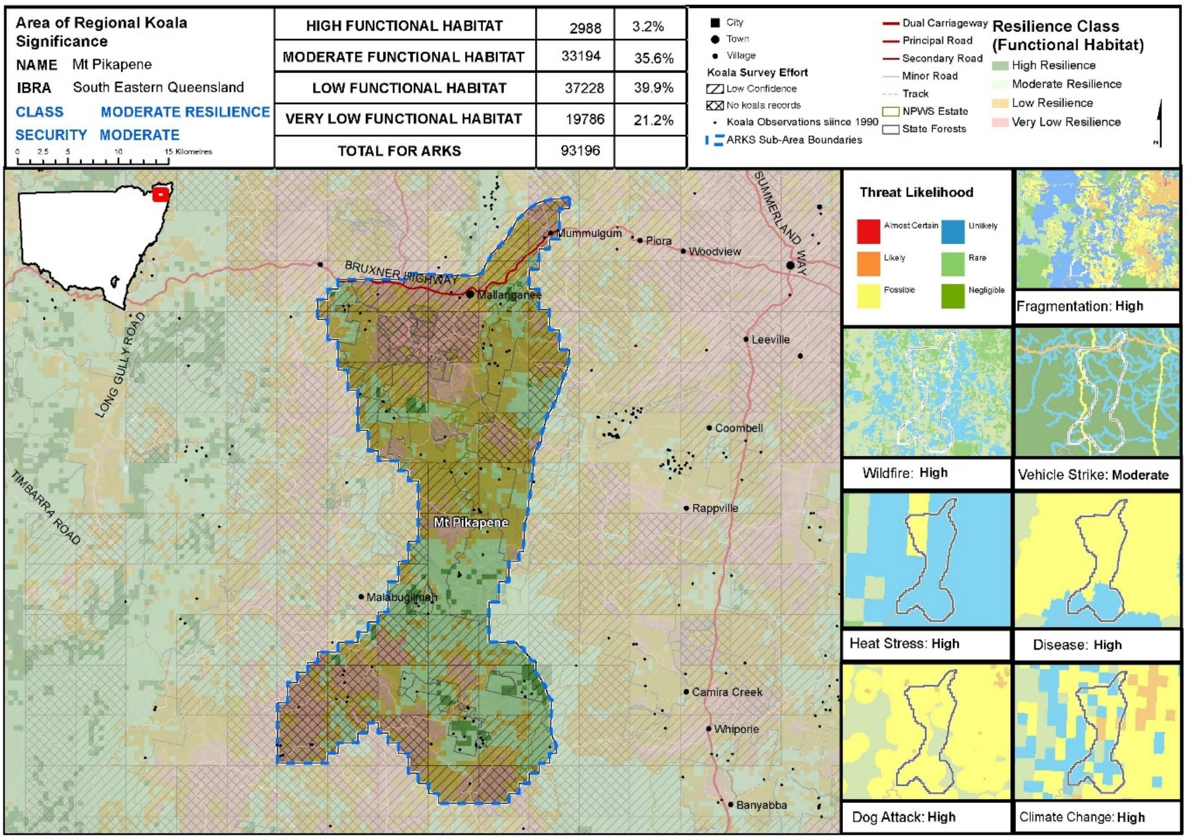
Map 24 Area of Regional Koala Significance Profile Map Kwiambal National Park



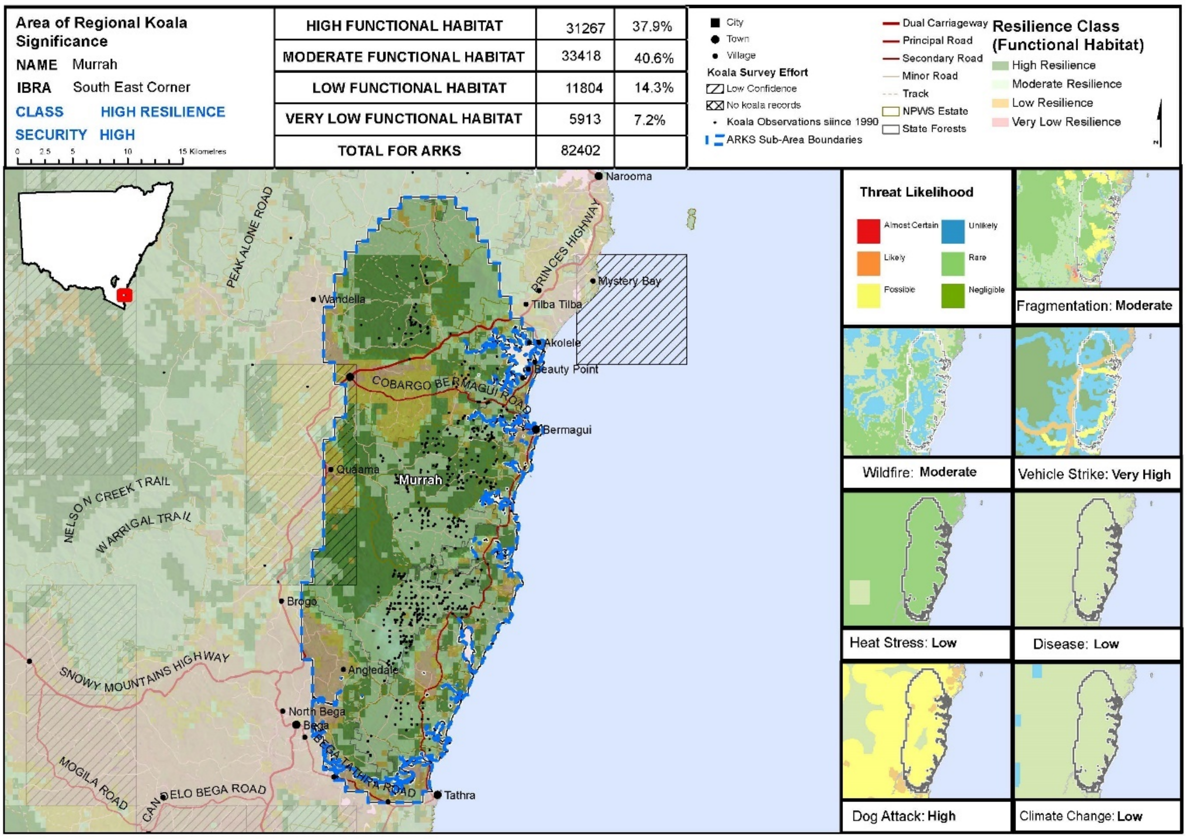
Map 25 Area of Regional Koala Significance Profile Map Lower Hunter



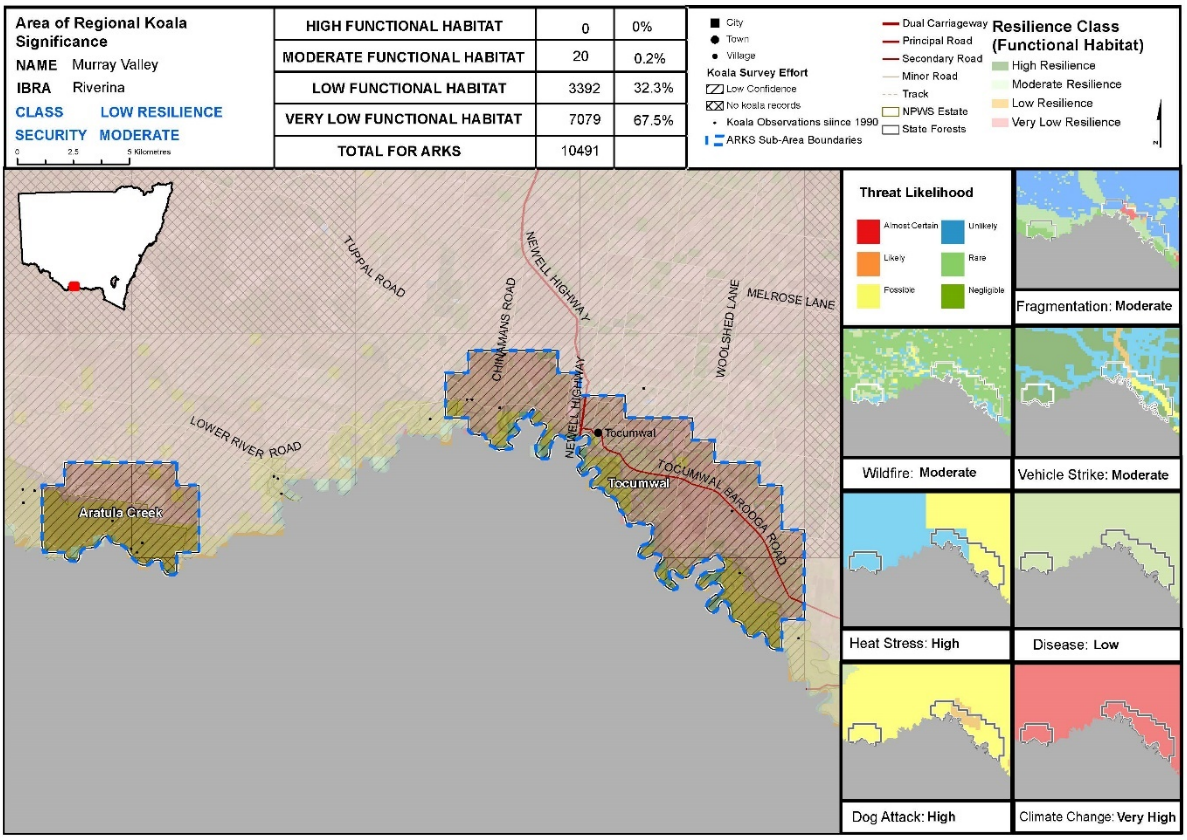
Map 26 Area of Regional Koala Significance Profile Map Moree



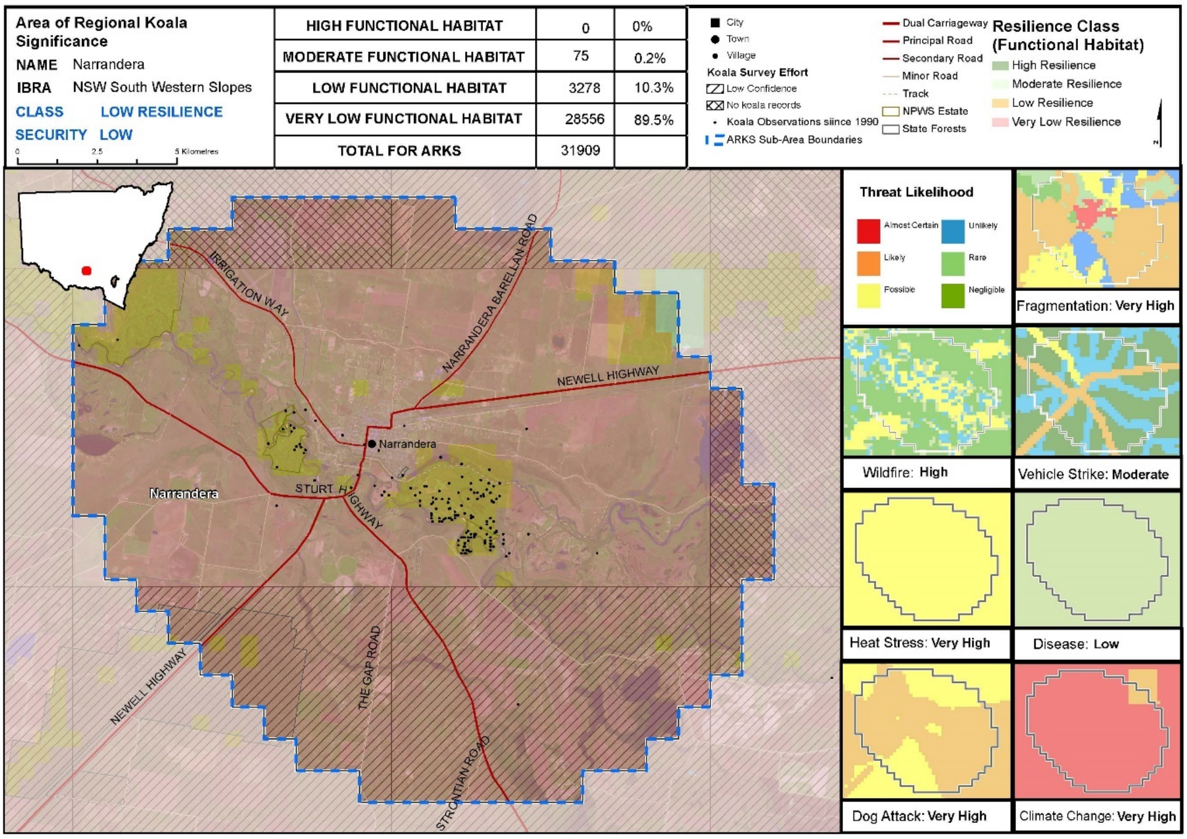
Map 27 Area of Regional Koala Significance Profile Map Mount Pikapene



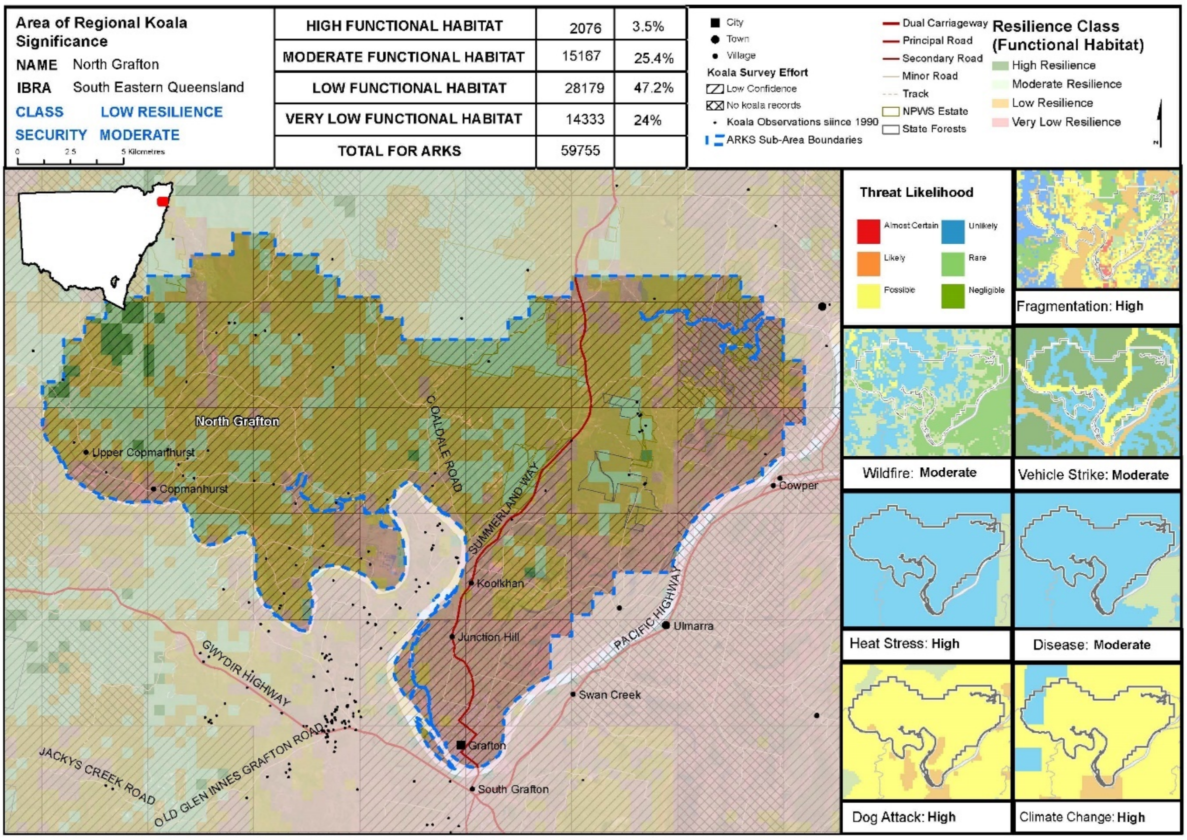
Map 28 **Area of Regional Koala Significance Profile Map Murrah**



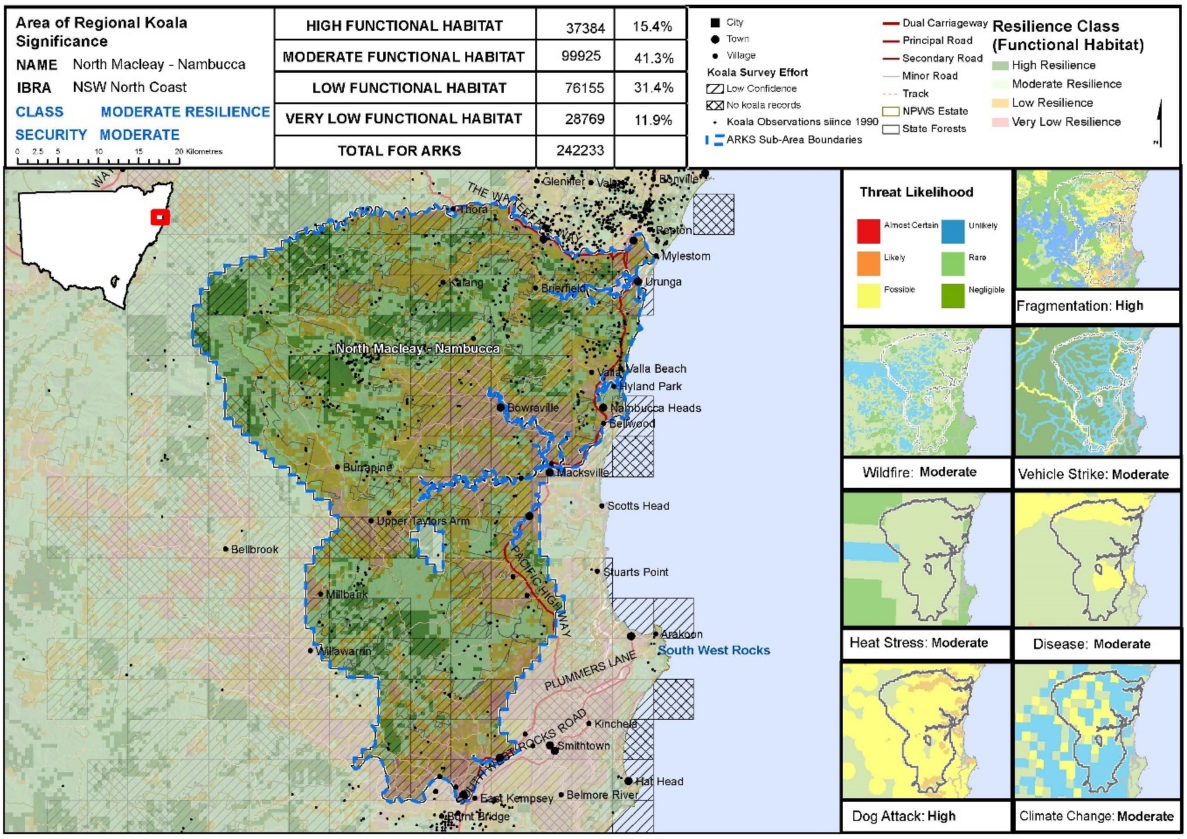
Map 29 **Area of Regional Koala Significance Profile Map Murray Valley**



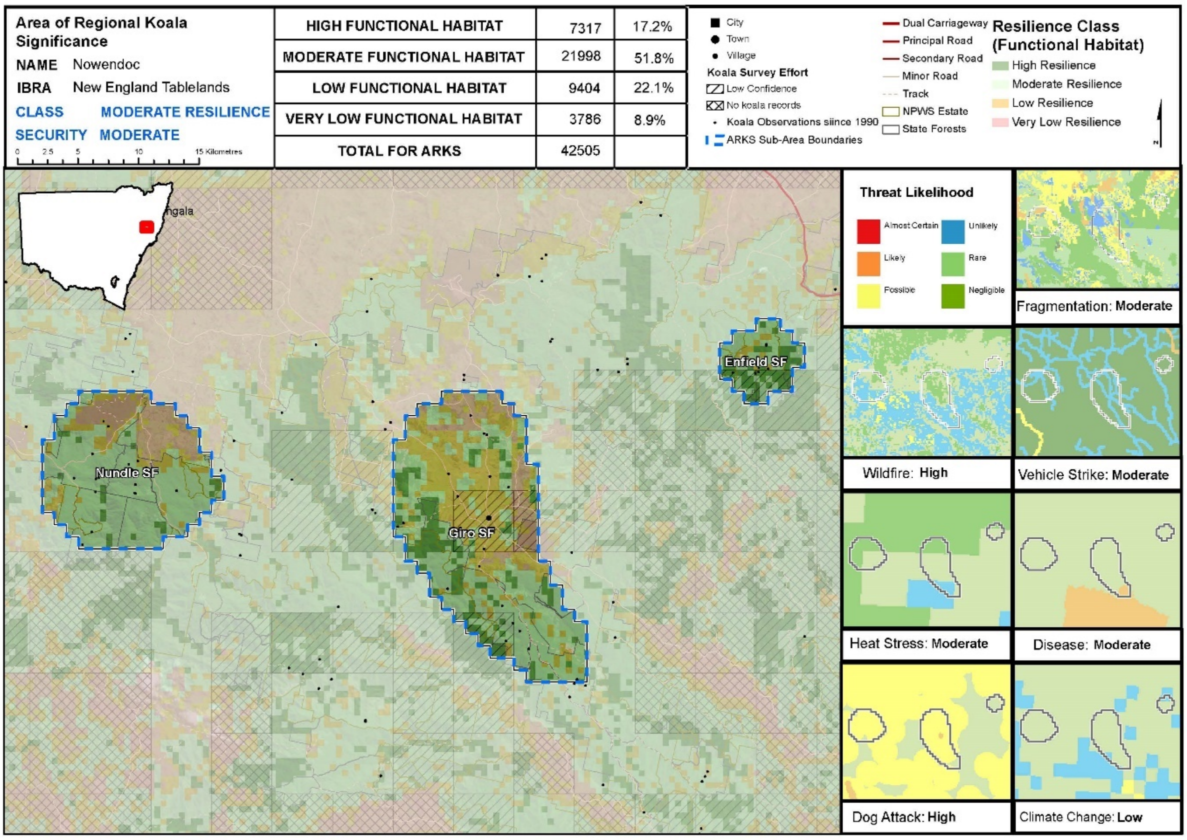
Map 30 Area of Regional Koala Significance Profile Map Narrandera



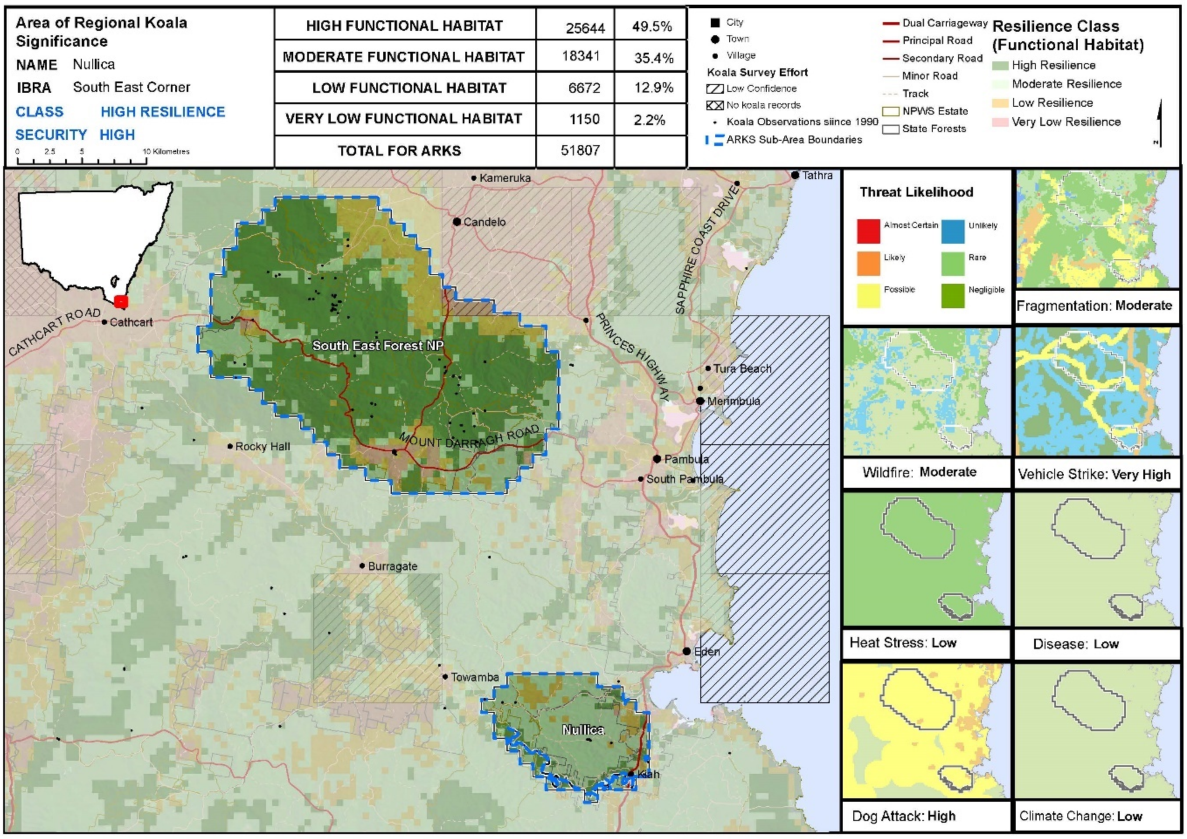
Map 31 Area of Regional Koala Significance Profile Map North Grafton



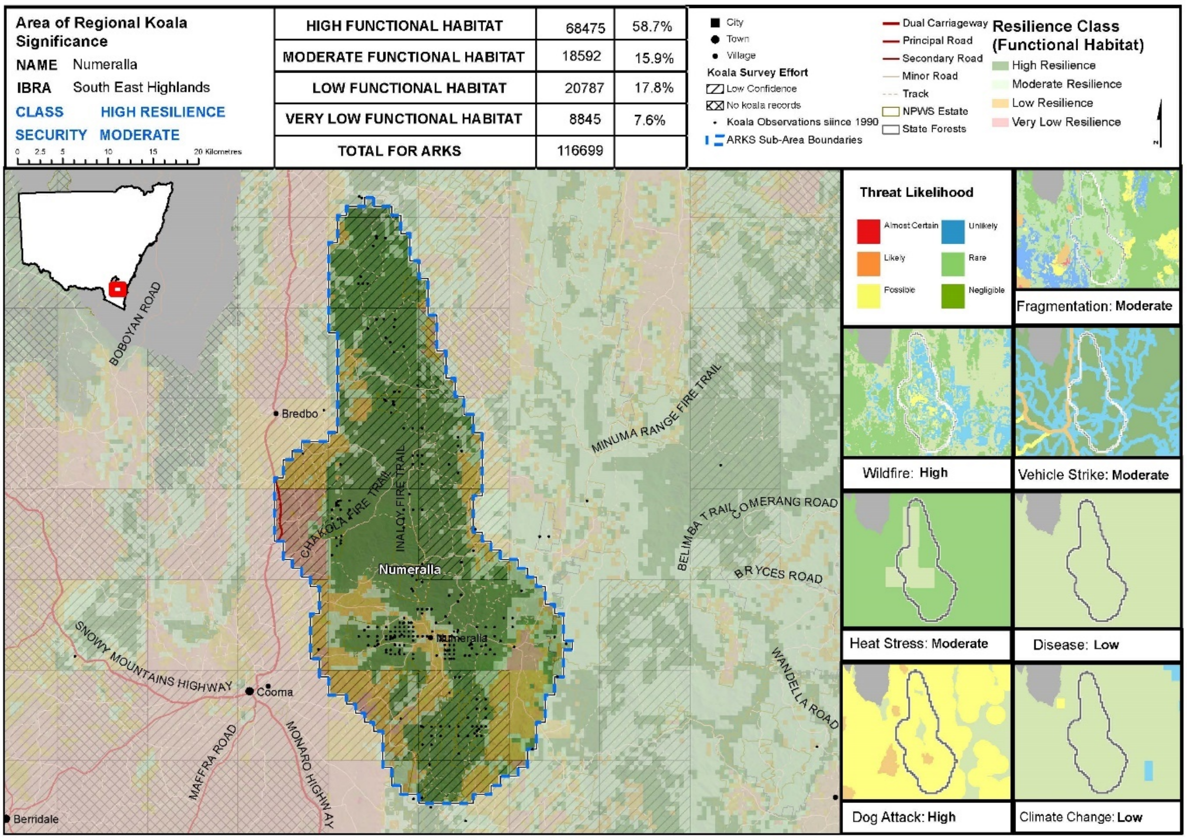
Map 32 Area of Regional Koala Significance Profile Map North Macleay – Nambucca



Map 33 Area of Regional Koala Significance Profile Map Nowendoc

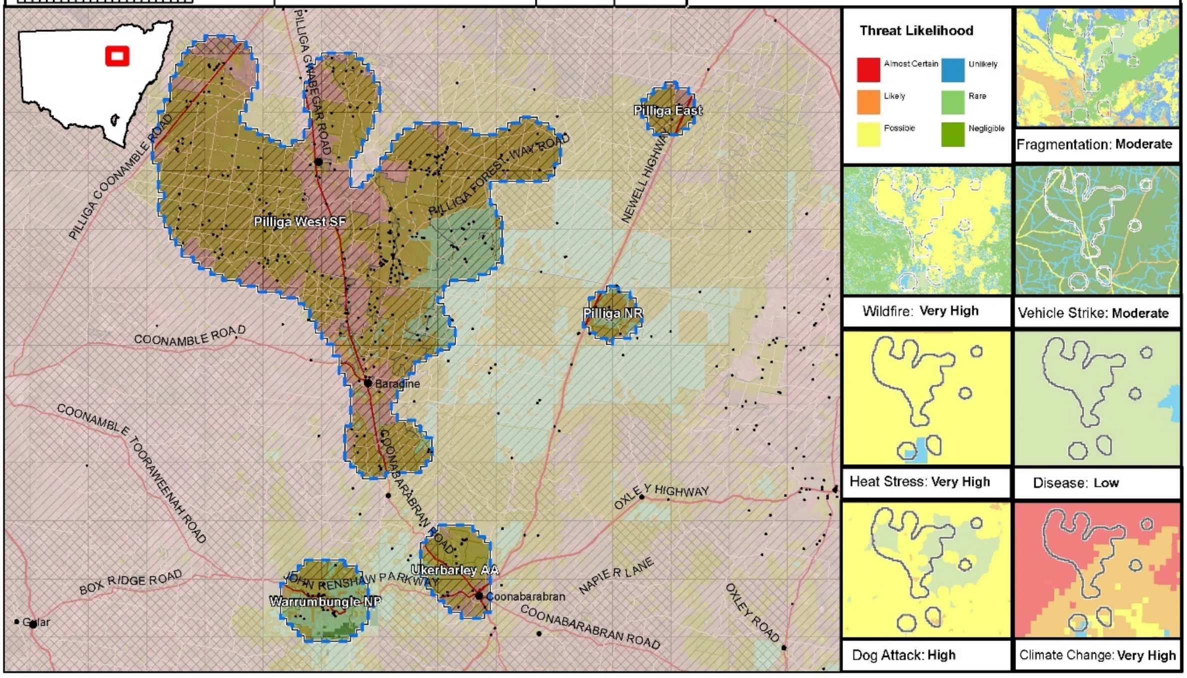


Map 34 Area of Regional Koala Significance Profile Map Nullica



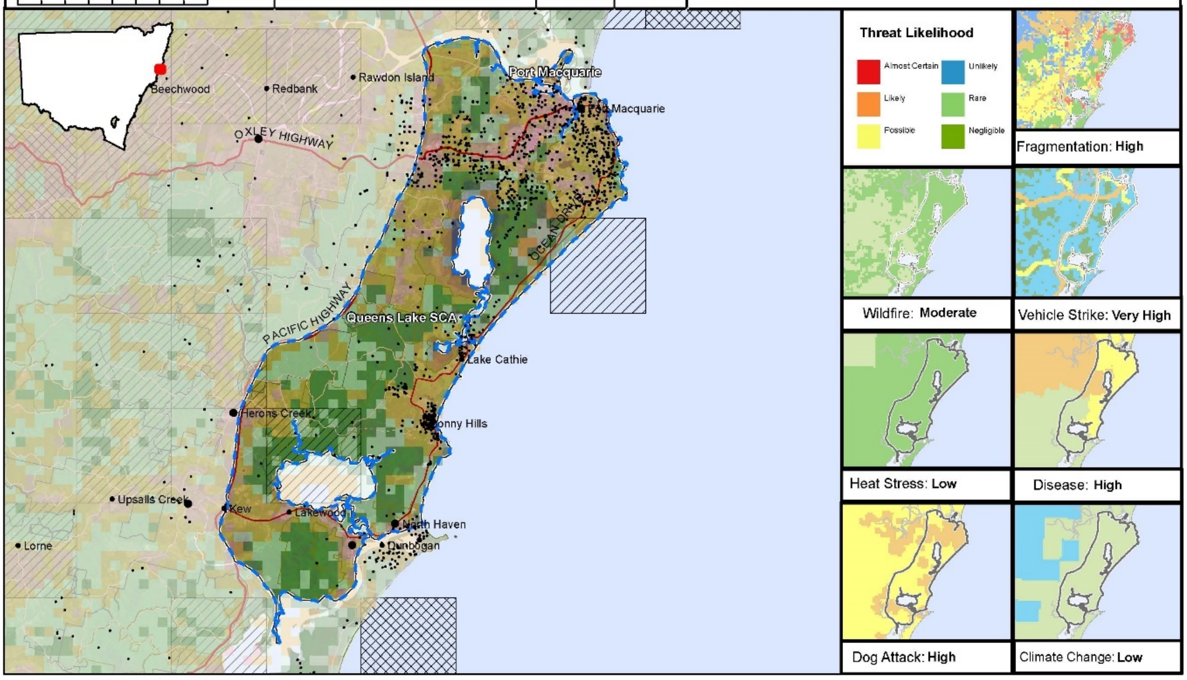
Map 35 Area of Regional Koala Significance Profile Map Numeralla

Area of Regional Koala Significance			
NAME: Pilliga	HIGH FUNCTIONAL HABITAT	845	0.3%
IBRA: Brigalow Belt South	MODERATE FUNCTIONAL HABITAT	63534	22.1%
CLASS: LOW RESILIENCE	LOW FUNCTIONAL HABITAT	168741	58.6%
SECURITY: HIGH	VERY LOW FUNCTIONAL HABITAT	54980	19.1%
	TOTAL FOR ARKS	288100	

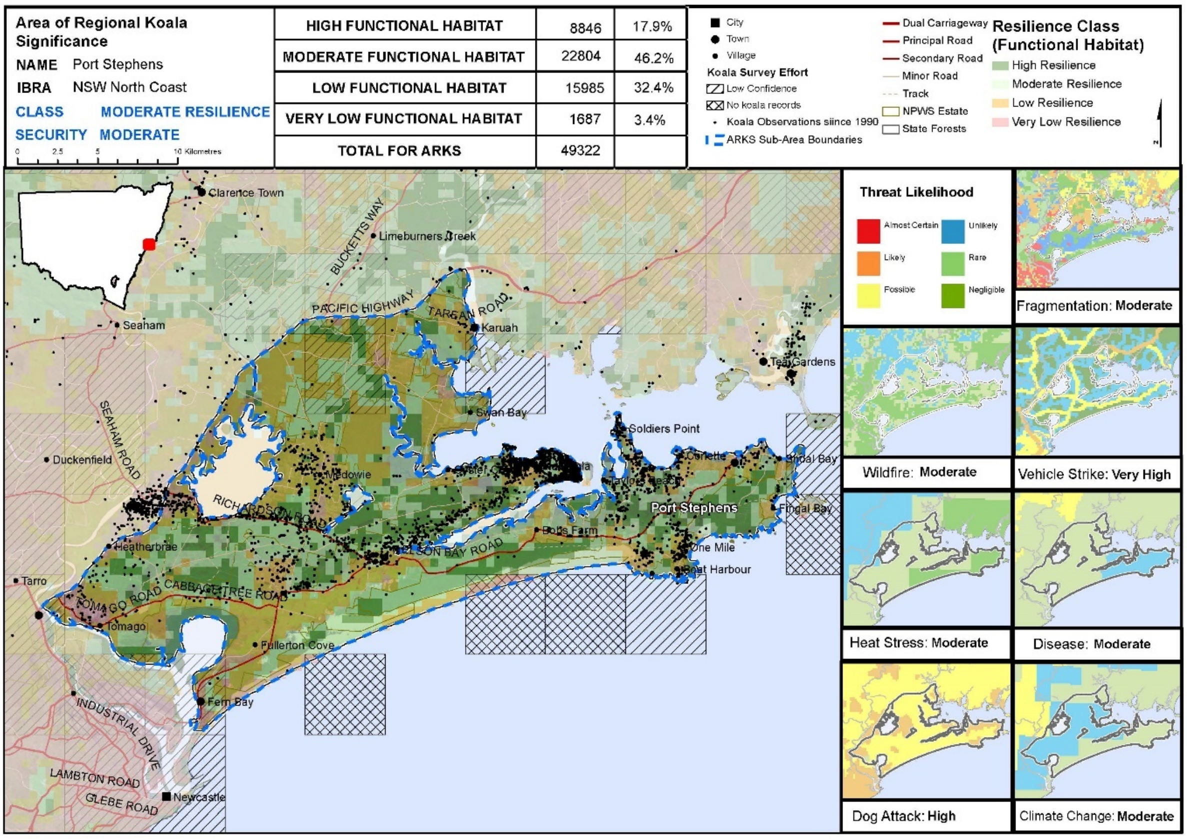


Map 36 Area of Regional Koala Significance Profile Map Pilliga

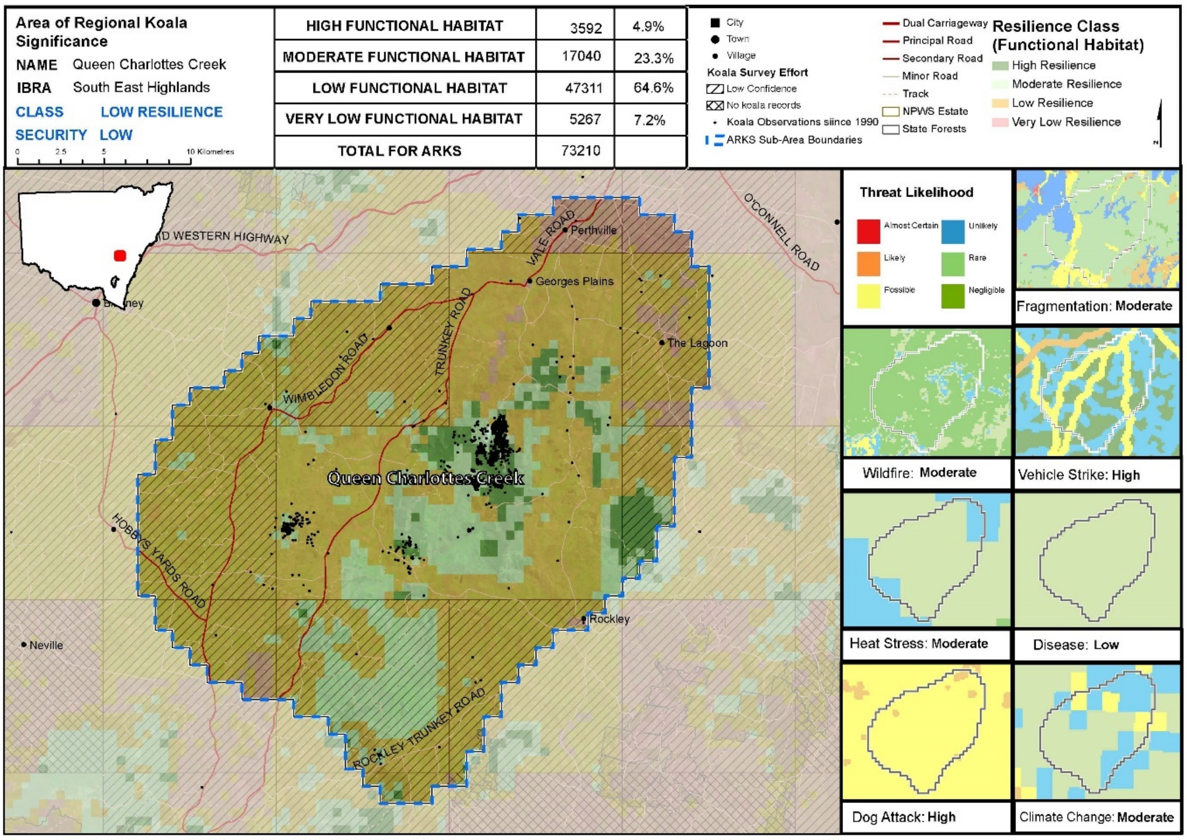
Area of Regional Koala Significance			
NAME: Port Macquarie	HIGH FUNCTIONAL HABITAT	6299	25.1%
IBRA: NSW North Coast	MODERATE FUNCTIONAL HABITAT	6598	26.2%
CLASS: MODERATE RESILIENCE	LOW FUNCTIONAL HABITAT	9029	35.9%
SECURITY: MODERATE	VERY LOW FUNCTIONAL HABITAT	3214	12.8%
	TOTAL FOR ARKS	25140	



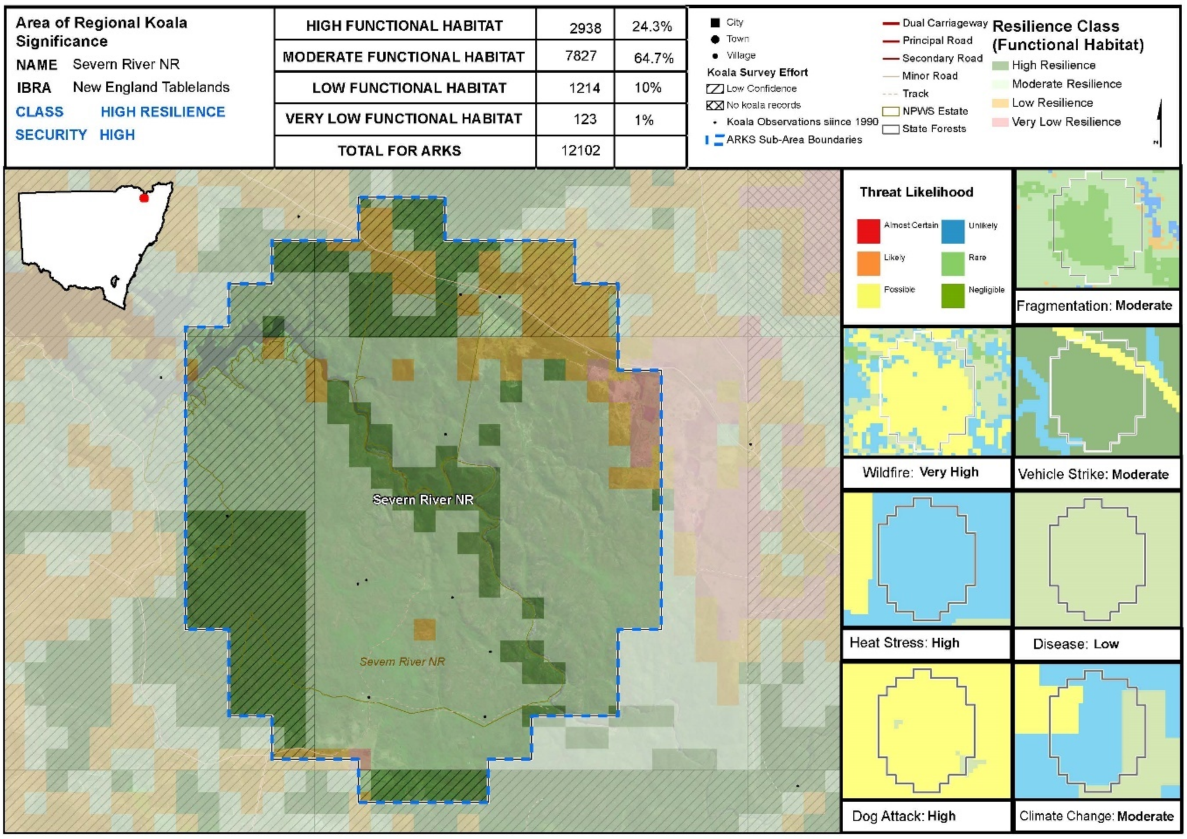
Map 37 Area of Regional Koala Significance Profile Map Port Macquarie



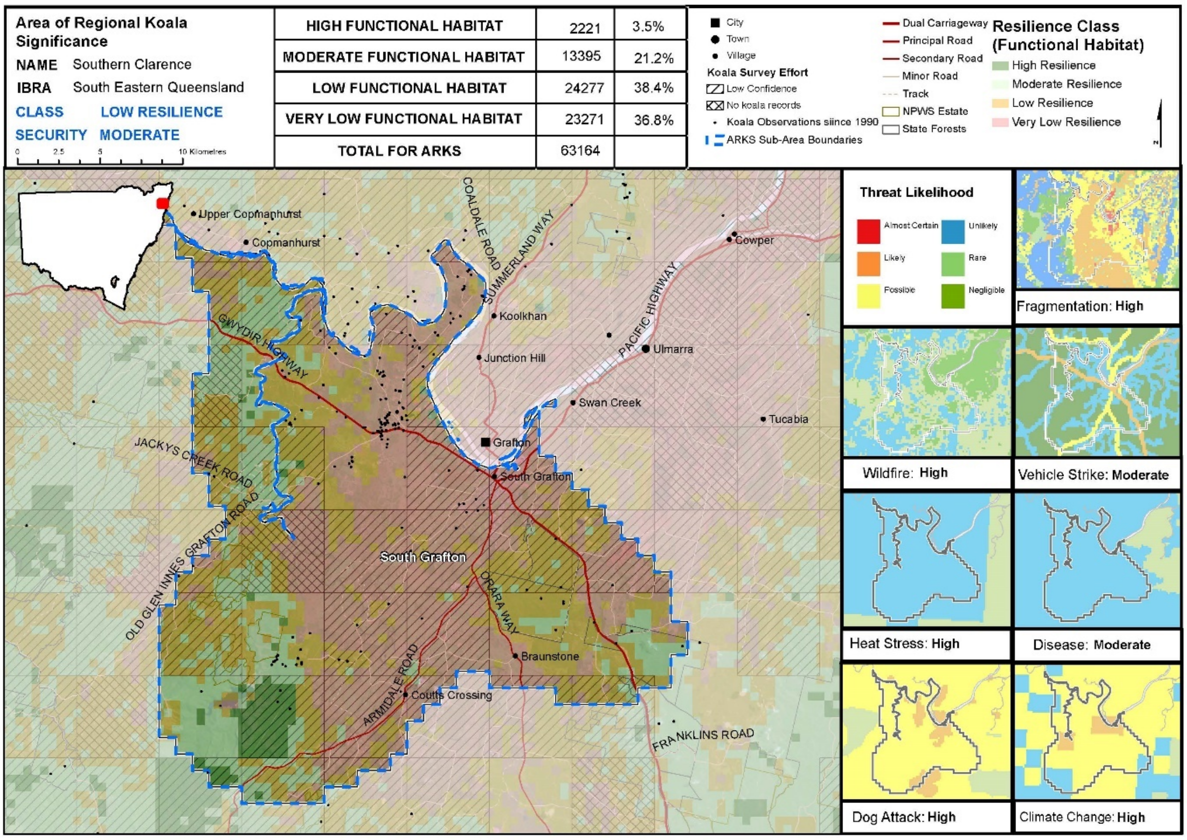
Map 38 Area of Regional Koala Significance Profile Map Port Stephens



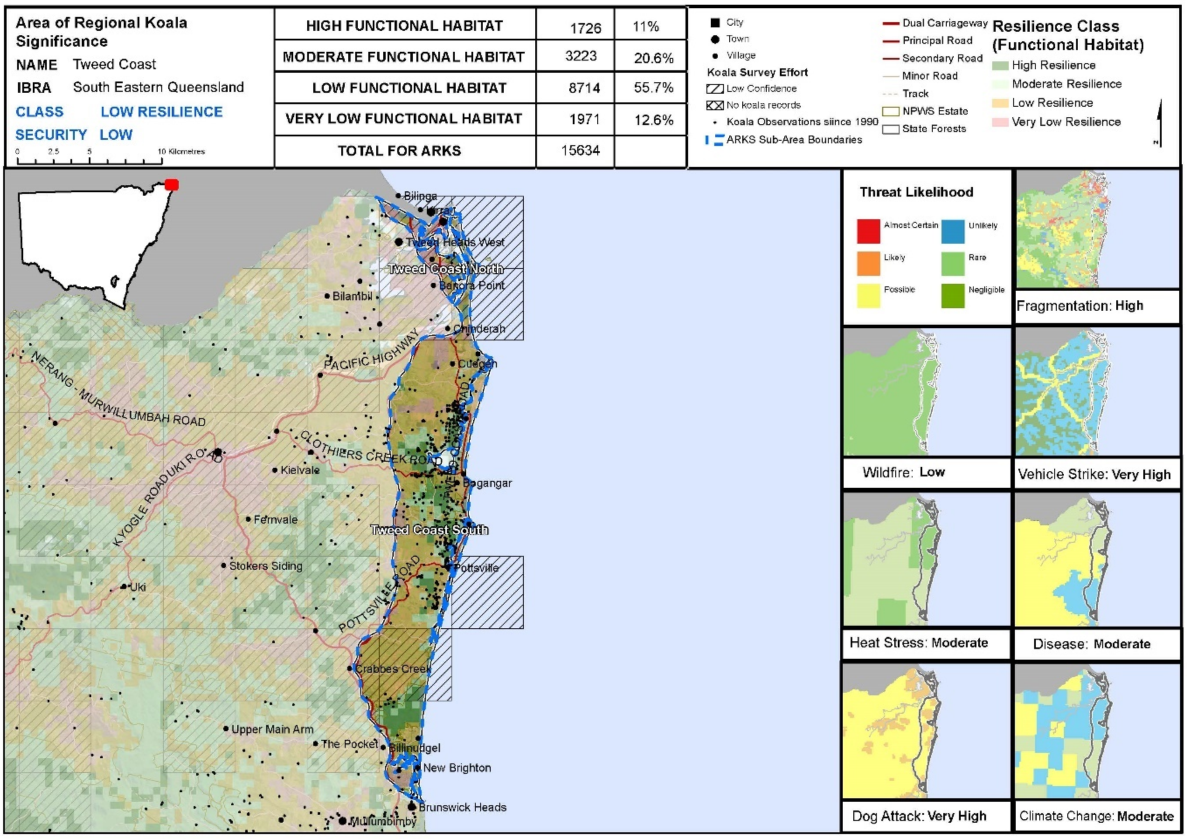
Map 39 Area of Regional Koala Significance Profile Map Queen Charlottes Creek



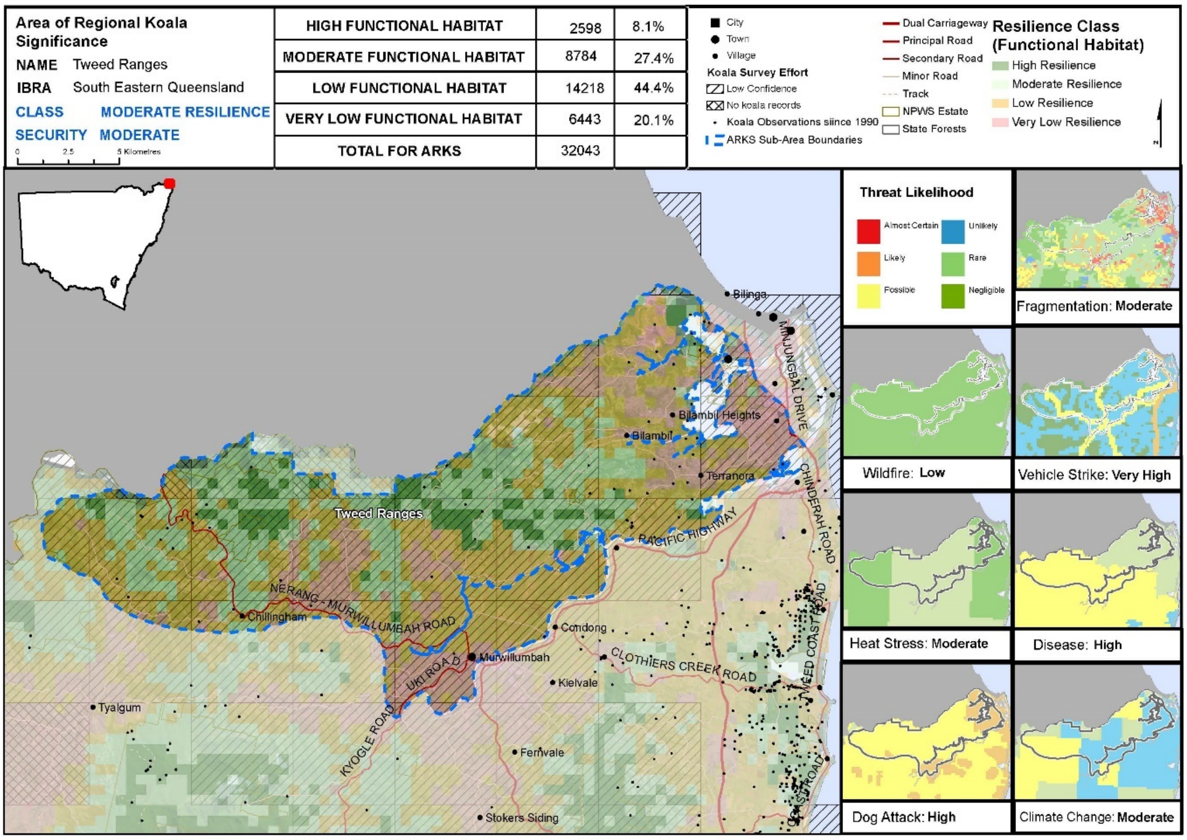
Map 40 **Area of Regional Koala Significance Profile Map Severn River Nature Reserve**



Map 41 **Area of Regional Koala Significance Profile Map Southern Clarence**

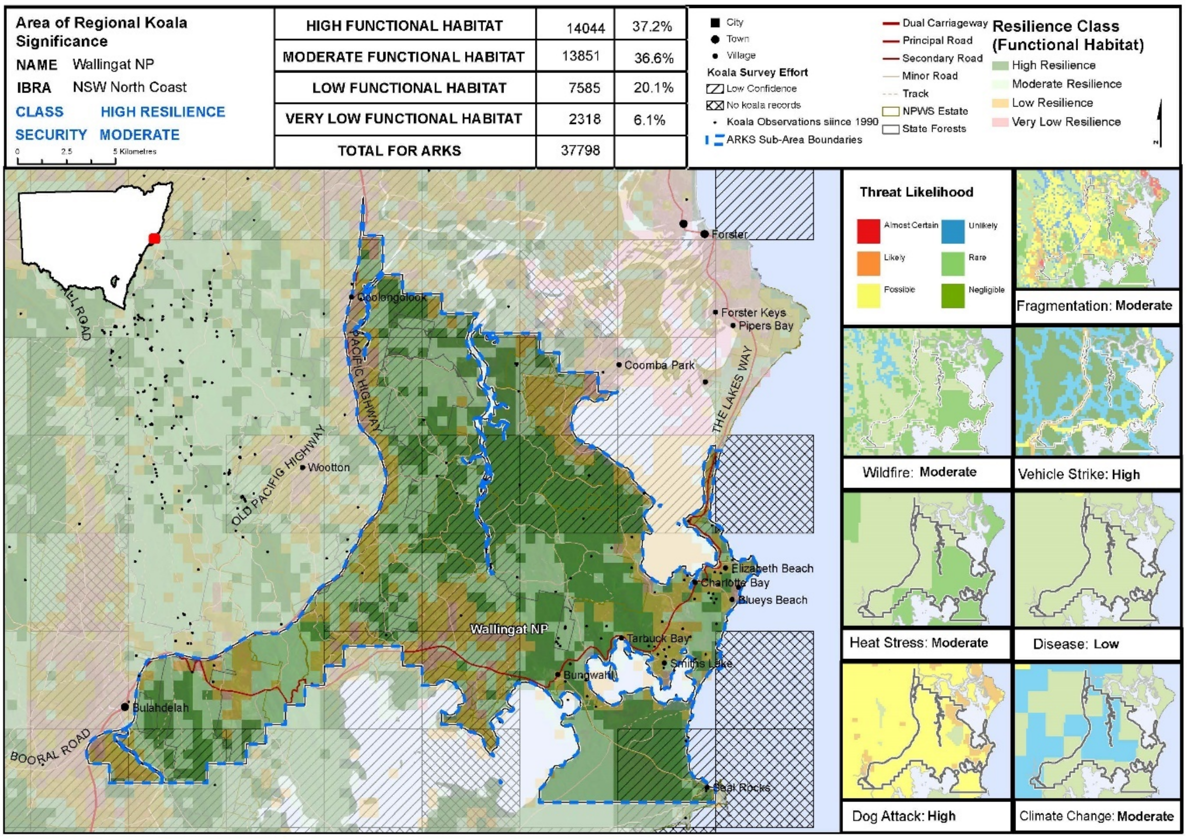


Map 42 **Area of Regional Koala Significance Profile Map Tweed Coast**



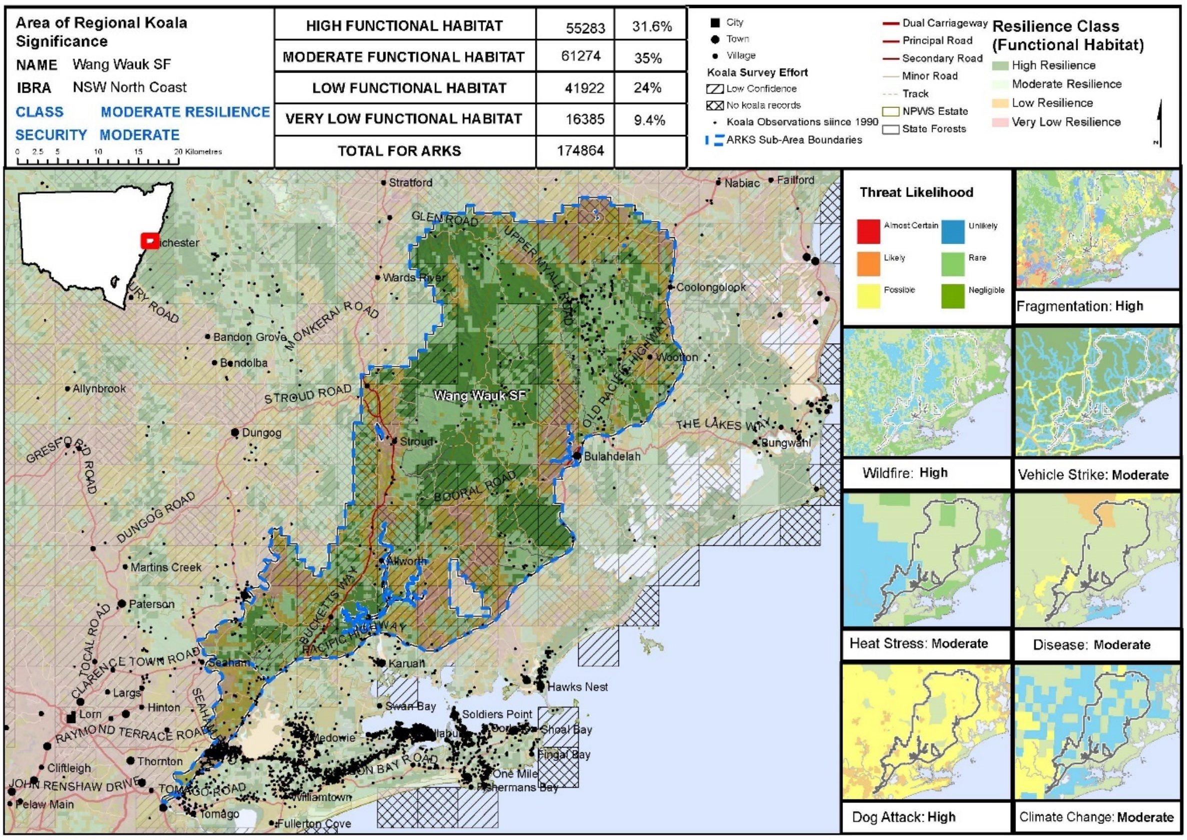
Map 43 **Area of Regional Koala Significance Profile Map Tweed Ranges**

Area of Regional Koala Significance			
NAME: Wallingat NP	HIGH FUNCTIONAL HABITAT	14044	37.2%
IBRA: NSW North Coast	MODERATE FUNCTIONAL HABITAT	13851	36.6%
CLASS: HIGH RESILIENCE	LOW FUNCTIONAL HABITAT	7585	20.1%
SECURITY: MODERATE	VERY LOW FUNCTIONAL HABITAT	2318	6.1%
	TOTAL FOR ARKS	37798	



Map 44 Area of Regional Koala Significance Profile Map Wallingat National Park

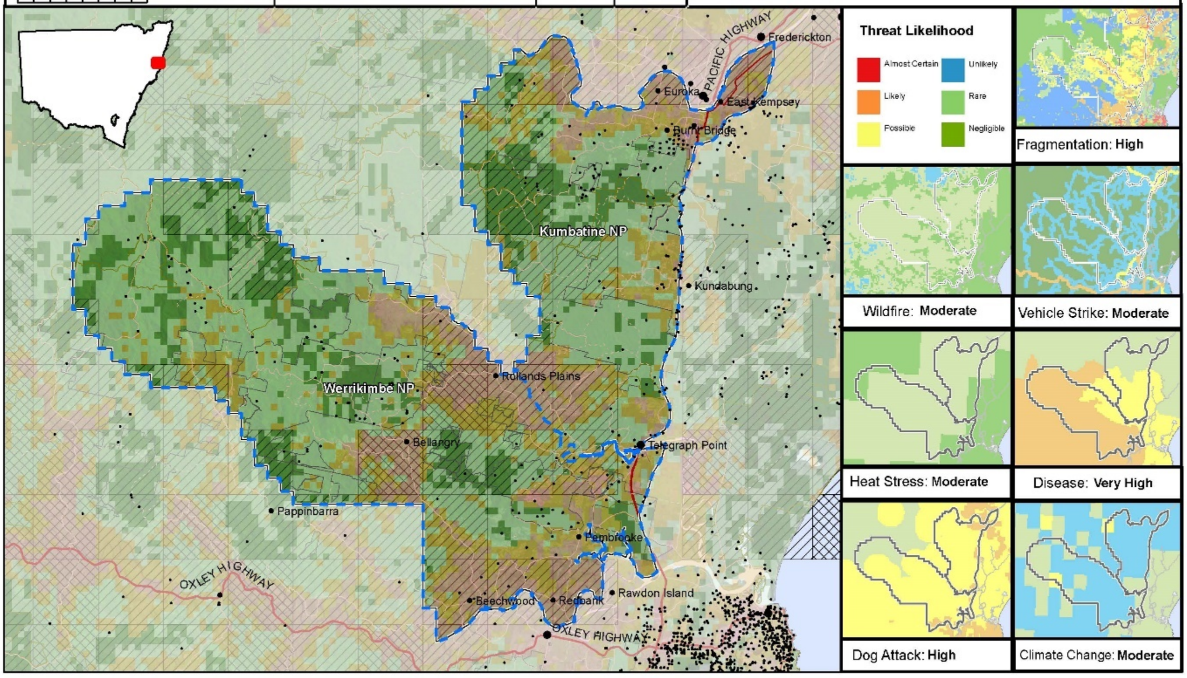
Area of Regional Koala Significance			
NAME: Wang Wauk SF	HIGH FUNCTIONAL HABITAT	55283	31.6%
IBRA: NSW North Coast	MODERATE FUNCTIONAL HABITAT	61274	35%
CLASS: MODERATE RESILIENCE	LOW FUNCTIONAL HABITAT	41922	24%
SECURITY: MODERATE	VERY LOW FUNCTIONAL HABITAT	16385	9.4%
	TOTAL FOR ARKS	174864	



Map 45 Area of Regional Koala Significance Profile Map Wang Wauk State Forest

Area of Regional Koala Significance
NAME Wilson River
IBRA NSW North Coast
CLASS MODERATE RESILIENCE
SECURITY MODERATE

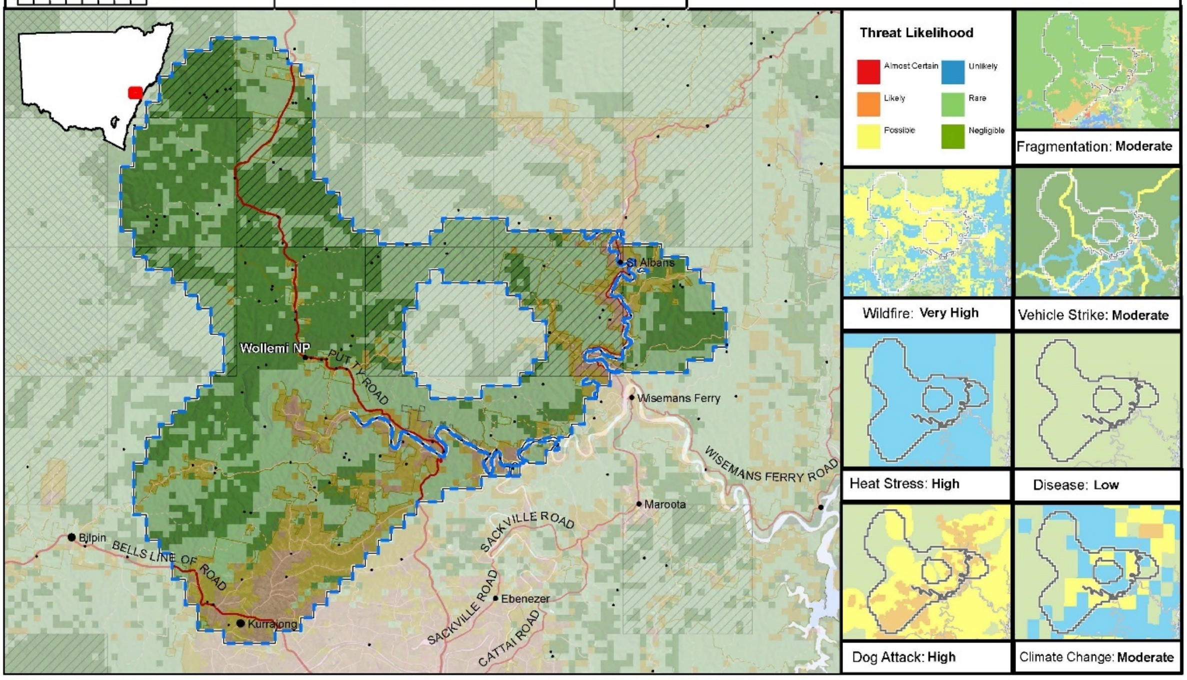
HIGH FUNCTIONAL HABITAT	18997	16.9%
MODERATE FUNCTIONAL HABITAT	54202	48.2%
LOW FUNCTIONAL HABITAT	23934	21.3%
VERY LOW FUNCTIONAL HABITAT	15299	13.6%
TOTAL FOR ARKS	112432	



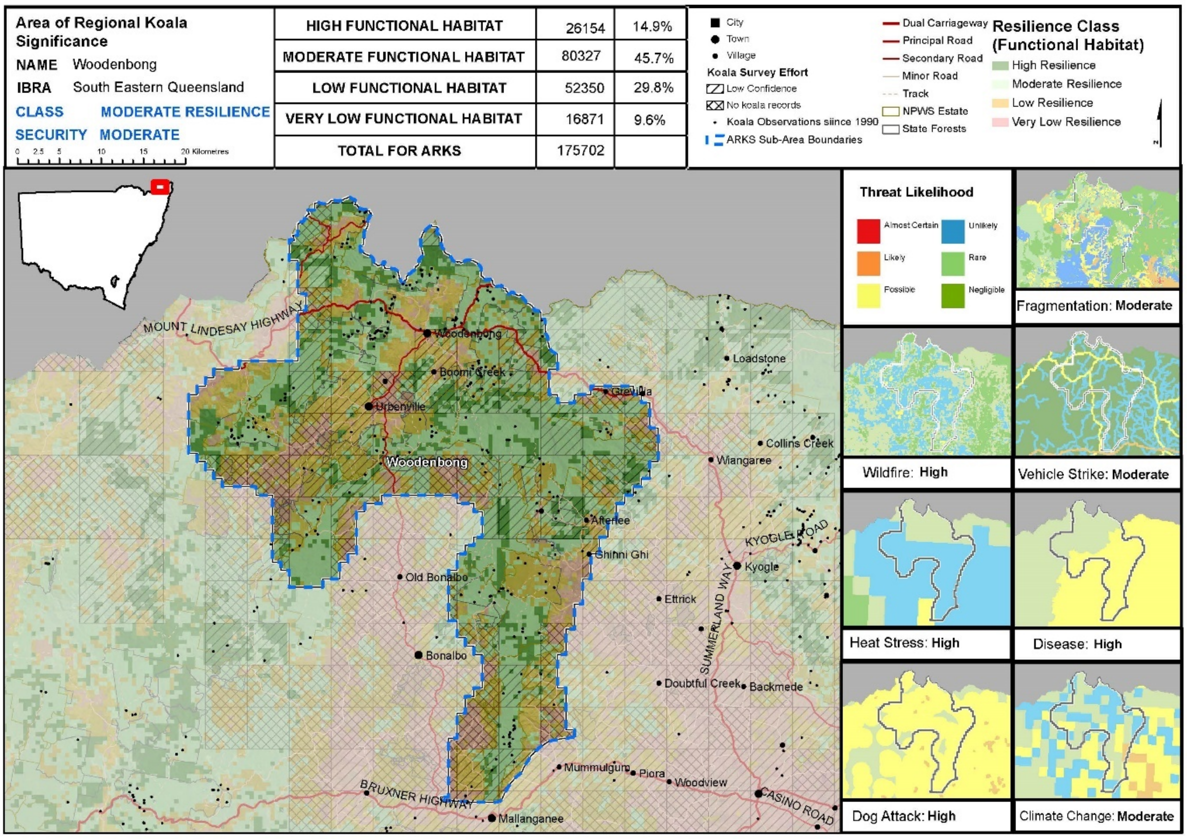
Map 46 Area of Regional Koala Significance Profile Map Wilson River

Area of Regional Koala Significance
NAME Wollemi NP
IBRA Sydney Basin
CLASS HIGH RESILIENCE
SECURITY HIGH

HIGH FUNCTIONAL HABITAT	39886	39.8%
MODERATE FUNCTIONAL HABITAT	39616	39.6%
LOW FUNCTIONAL HABITAT	14825	14.8%
VERY LOW FUNCTIONAL HABITAT	5767	5.8%
TOTAL FOR ARKS	100094	



Map 47 Area of Regional Koala Significance Profile Map Wollemi National Park



Map 48 **Area of Regional Koala Significance Profile Map Woodenbong**

Appendix B Threat versus values – matrix of risk scores

Appendix B contains a risk score matrix for each threat against koala values. It is used to apply numerical modifiers to mapped koala values to determine their resilience to current and future threats.

Table B.1 Threat versus values – matrix of risk scores

Threat group	Value	Likelihood				
		Rare	Unlikely	Possible	Likely	Almost certain
Habitat loss, fragmentation and degradation	Forest maturity	Minimal	Low	Moderate	High	High
	Refugia	Minimal	Low	Moderate	High	High
	Connectivity and integrity	Minimal	Low	Moderate	High	High
	Habitat suitability	Minimal	Low	Moderate	High	High
	Occupancy	Minimal	Minimal	Low	Moderate	Moderate
Urbanisation	Forest maturity	Low	Moderate	High	High	Very high
	Refugia	Low	Moderate	High	High	Very high
	Connectivity and integrity	Low	Moderate	High	High	Very high
	Habitat suitability	Low	Moderate	High	High	Very high
	Occupancy	Minimal	Low	Moderate	High	High
Collisions with motor vehicles	Forest maturity	Minimal	Minimal	Minimal	Minimal	Minimal
	Refugia	Minimal	Minimal	Minimal	Minimal	Minimal
	Connectivity and integrity	Minimal	Low	Moderate	High	High
	Habitat suitability	Minimal	Minimal	Minimal	Minimal	Minimal
	Occupancy	Minimal	Low	Moderate	High	High
Predation by wild or domestic dogs	Forest maturity	Minimal	Minimal	Minimal	Minimal	Minimal
	Refugia	Minimal	Minimal	Minimal	Minimal	Minimal
	Connectivity and integrity	Minimal	Low	Moderate	High	High

Threat group	Value	Likelihood				
		Rare	Unlikely	Possible	Likely	Almost certain
	Habitat suitability	Minimal	Minimal	Minimal	Minimal	Minimal
	Occupancy	Minimal	Minimal	Low	Moderate	Moderate
Wildfire and intense prescribed burns	Forest maturity	Minimal	Low	Moderate	High	High
	Refugia	Minimal	Minimal	Minimal	Low	Low
	Connectivity and integrity	Minimal	Minimal	Minimal	Low	Low
	Habitat suitability	Minimal	Minimal	Minimal	Low	Low
	Occupancy	Minimal	Low	Moderate	High	High
Heatwave	Forest maturity	Minimal	Minimal	Low	Moderate	Moderate
	Refugia	Minimal	Minimal	Minimal	Minimal	Minimal
	Connectivity and integrity	Minimal	Minimal	Minimal	Minimal	Minimal
	Habitat suitability	Minimal	Minimal	Minimal	Minimal	Minimal
	Occupancy	Minimal	Low	Moderate	High	High
Disease	Forest maturity	Minimal	Minimal	Minimal	Minimal	Minimal
	Refugia	Minimal	Minimal	Minimal	Minimal	Minimal
	Connectivity and integrity	Minimal	Minimal	Minimal	Minimal	Minimal
	Habitat suitability	Minimal	Minimal	Minimal	Minimal	Minimal
	Occupancy	Minimal	Minimal	Low	Moderate	Moderate
Reduction in suitability of habitat from the effects of climate change	Forest maturity	Minimal	Minimal	Minimal	Minimal	Minimal
	Refugia	Minimal	Low	Moderate	High	High
	Connectivity and integrity	Minimal	Minimal	Minimal	Minimal	Minimal
	Habitat suitability	Low	Moderate	High	High	Very high
	Occupancy	Low	Moderate	High	High	Very high

Appendix C Areas of Regional Koala Significance – resilience categories

Of the 48 areas of regional koala significance recognised by this study in New South Wales, 13 have been ranked as high resilience, 22 as moderate resilience and 13 as low resilience. The table in this appendix displays the resilience rank for each area (in alphabetical order). The resilience class is a function of the values (habitat and occupancy) and the level of risk they are exposed to by threatening processes (refer to the glossary for more information).

ARKS name	High resilience	Moderate resilience	Low resilience
Armidale			1
Banyabba		1	
Barrington		1	
Belmore River		1	
Blaxland		1	
Brisbane Water NP	1		
Broadwater		1	
Bungonia		1	
Clouds Creek	1		
Coffs Harbour – North Bellingen		1	
Comboyne		1	
Crowdy Bay	1		
Far north-east			1
Far north-east Hinterland		1	
Gibraltar Range	1		
Girard – Ewingar	1		
Gunnedah			1
Hawks Nest	1		
Inverell			1
Karuah – Myall Lakes		1	
Khappinghat		1	
Killarney			1
Kiwarrak		1	
Kwiambal NP		1	
Lower Hunter	1		
Moree			1
Mt Pikapene		1	
Murrah	1		
Murray Valley			1

ARKS name	High resilience	Moderate resilience	Low resilience
Narrandera			1
North Grafton			1
North Macleay – Nambucca		1	
Nowendoc		1	
Nullica	1		
Numeralla	1		
Pilliga			1
Port Macquarie		1	
Port Stephens		1	
Queen Charlottes Creek			1
Severn River NR	1		
Southern Clarence			1
Tweed Coast			1
Tweed Ranges		1	
Wallingat NP	1		
Wang Wauk SF		1	
Wilson River		1	
Wollemi NP	1		
Woodenbong		1	
Total	13	22	13

Appendix D Areas of Regional Koala Significance – security categories

Of the 48 areas of regional koala significance recognised by this study in New South Wales, eight have been ranked with high security, 28 with moderate security and 12 with low security. The table in this appendix displays the security rank for each area (in alphabetical order). ARKS security has been assessed as a function of predicted sensitivity to loss and the land tenure status of koalas (refer to the glossary for more information).

ARKS name	High security	Moderate security	Low security
Armidale			1
Banyabba			1
Barrington			1
Belmore River			1
Blaxland			1
Brisbane Water NP	1		
Broadwater		1	
Bungonia		1	
Clouds Creek		1	
Coffs Harbour – North Bellingen		1	
Comboyne		1	
Crowdy Bay	1		
Far north-east		1	
Far north-east Hinterland		1	
Gibraltar Range	1		
Girard – Ewingar		1	
Gunnedah		1	
Hawks Nest			1
Inverell			1
Karuah – Myall Lakes		1	
Khappinghat		1	
Killarney			1
Kiwarrak		1	
Kwiambal NP		1	
Lower Hunter		1	
Moree			1
Mt Pikapene		1	
Murrah	1		
Murray Valley		1	
Narrandera			1

ARKS name	High security	Moderate security	Low security
North Grafton		1	
North Macleay – Nambucca		1	
Nowendoc		1	
Nullica	1		
Numeralla		1	
Pilliga	1		
Port Macquarie		1	
Port Stephens		1	
Queen Charlottes Creek			1
Severn River NR	1		
Southern Clarence		1	
Tweed Coast			1
Tweed Ranges		1	
Wallingat NP		1	
Wang Wauk SF		1	
Wilson River		1	
Wollemi NP	1		
Woodenbong		1	
Total	8	28	12

Appendix E Spatial analysis of population threats and values

This appendix presents the method and results for the analysis of koala values and threats. For each of the values and threats, a concise profile has been compiled, including the rationale for analysis, the analysis method and the resultant map and map categories.

The analysis of resilience of koala populations and areas of interest has been broken down into two broad components: values assessment and threats assessment.

This section presents the method and results for the analysis of koala values and threats. A concise profile has been compiled for each of the values and threats, including the rationale for analysis, the analysis method and the resultant map and map categories.

An assessment was done of the current habitat and landscape context attributes of the koala population. Table E.1 lists the five mapped values contributing to the values integrity mapping. Each value is described in more detail in the following section.

Table E.1 Five key criteria for scoring of koala habitat values

Value title	Brief description	Dataset/s	Weighting
Forest maturity	Structural integrity of habitat	SLATS clearing history and extant vegetation	Moderate – Low (0.5)
Landscape integrity	Broader landscape connectivity of population to wider habitat areas	Patch size class from current extant vegetation	Moderate – Low (0.5)
Habitat suitability	Potential habitat suitability	Habitat suitability class interpreted from Keith 2004	High (1.5)
Riparian refugia	Quality and access to refugia within and adjacent to population habitat area	Perennial stream class, water features (natural and constructed) and patch size class	Moderate (1.0)
Occupancy	Areas of demonstrated occupation by koalas	Koala likelihood of occurrence grid (10 km and 5 km for north coast)	High (1.5)

Threats and threatening processes which act on the koalas, or which have the potential to influence koalas in the future, have been assessed at a regional scale. In all, seven threat groups have been identified from a larger list published in a report by Smith, Lunney and Moon (2016). A brief description of each threat group and datasets used are listed in Table E.2. A full description of each threat group and mapping is presented in the section following.

Table E.2 Seven criteria for spatial scoring of threat modifiers

Threat title	Brief description	Dataset/s
Habitat loss and fragmentation	Likelihood of loss from land use change and current land use pressures. Pressures include agricultural activities, mining activities and logging	Compilation of over 20 separate datasets which influence land management, development, historical clearing and forestry practices
Wildfire	Likelihood of mortality and habitat loss from high intensity wildfire and prescribed burning	Fuel load class (Vortex) and predicted future frequency of

Threat title	Brief description	Dataset/s
		High Forest Fire Danger Index days per annum
Vehicle strike	Likelihood of mortality from collision with motor vehicles	Road classification data and proximity analysed habitat
Dog attack	Likelihood of mortality from dog attack (wild or domestic)	Proximity of habitat to urban land, rural residential land and mapped rural homesteads
Disease	Likelihood of sickness or mortality from disease (including chlamydia)	Rate of care group recorded sickness and mortality from disease
Heat stress and drought	Likelihood of heatwave and drought resulting in sickness and mortality	Future predicted frequency of heat stress events (days over 35°C) (NARCliM model)
Reduction in the suitability of habitat from the effects of climate change	Likelihood of the reduction in the suitability of habitat for koalas because of human-induced climate change	Future predicted reduction in the suitability of habitat for koalas (Briscoe et al. 2016)

Other threats recognised by Smith, Lunney and Moon (2016) such as cyclones, over-browsing and leaf chemistry changes were deemed less relevant for NSW koala populations and/or (in the case of leaf chemistry changes), too difficult to map.

Values assessment profiles

Forest maturity

Rationale

The structure of the forest canopy has been demonstrated to be linked to preference by koalas, with usage by koalas most common in trees of mature and senescent growth stages (over 30 cm). Forests with dominant mature and senescent growth stage and lower associated disturbance evidence are therefore presumed to have higher value for habitat. The NSW Koala Recovery Plan (DECC 2008) comments that many studies point to a preference for koalas utilising larger diameter trees.

Background

Studies done at Pine Creek State Forest (6400 ha in north-east NSW) showed koala preferred structurally complex forests (uneven ages, with old growth elements and high species diversity). Habitat preferences favoured areas with larger tree (40–80 cm) (Smith 2004).

Large areas of coastal NSW (north coast, northern tablelands, southern tablelands and south coast) have growth stage mapping associated with the Regional Forest Agreement process. Now 20 years old, this data has limited usefulness for predicting canopy structure and growth stage. More recent projects have been undertaken on a local and property scale to update and refine this older data. Coffs Harbour City Council, in association with the Department of Planning, Industry and Environment, undertook a project in 2014 to map forest senescence and disturbance at fine-scale over freehold land in the council area (Cotsell et al. 2014). The overall area covered by recent growth stage mapping remains small in proportion to the total landscape.

Woody change data has been collected by OEH Science Division since 1988, captured from Landsat TM at a resolution of 25 metres (processed by Geoscience Australia). The change data are based on annual and bi-annual coverages of Landsat imagery over the period. The major categories assigned to the woody change (loss) are fire activity, agricultural activity, infrastructure and forestry activity.

Analysis approach and datasets

The approach of this analysis is to utilise current extant native woody mapping and historical vegetation clearing data to categorise koala population areas into a value range reflective of their likely habitat value for koalas. Areas of current native vegetation which have a mapped clearing event since 1988 are considered to be regrowth. Analysis grids have been classified according to the proportion of regrowth they contain.

Table E.3 Habitat fragmentation and clearing value assessment

Maturity class	Maturity class description	Value score
High	Predominantly (>70%) mature forest	1.0
Moderate	Mixed (30–70%) mature and regrowth forest	0.75
Low	Predominantly young forest or recently disturbed forest	0.5

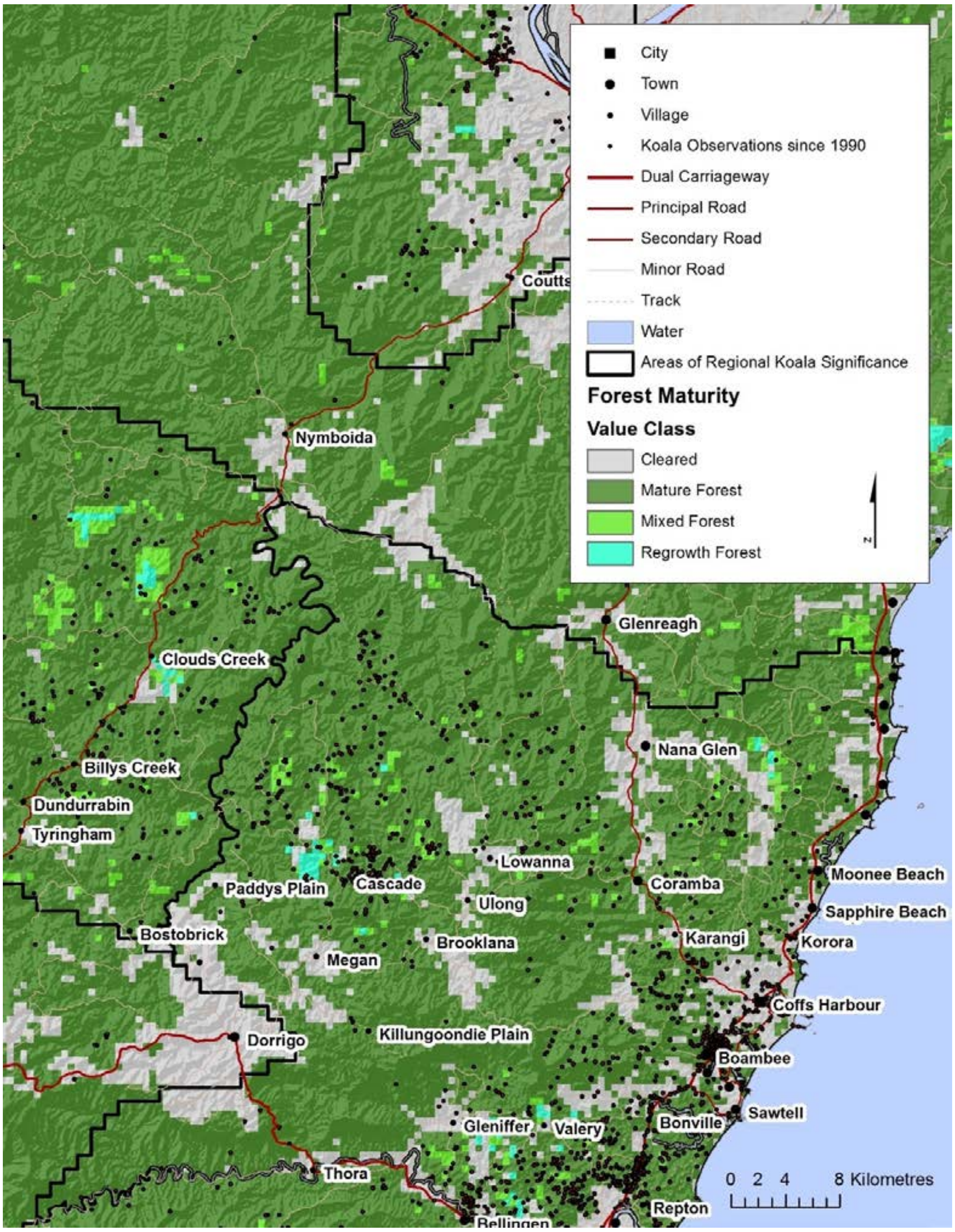


Figure E 1 Forest maturity for Coffs Harbour – North Bellingen ARKS

Landscape integrity

Rationale

The distribution of habitat as measured by patch size has been found to be an important measure of occupancy by koalas. Local extinctions of koala sub-populations have occurred in the past and have highlighted the need for recognition of koala sub-population structure, and the need for facilitating movements of individuals between smaller areas (Curtin, Lunney & Matthews 2002).

Vegetated linkage areas are important for koalas to survive. Where dispersal and recruitment are impeded by barriers such as open areas and roads, koala populations would be expected to decline (DECC 2008).

Background

Land clearing has been a significant cause of koala mortality (Cogger et al. 2003). Local extinctions of koala sub-populations have occurred in the past and have highlighted the need for recognition of koala sub-population structure, and the need for facilitating movements of individuals between smaller areas (Curtin, Lunney & Matthews 2002).

The distribution of habitat as measured by patch size has been found to be an important measure of occupancy by koalas. A study by McAlpine (McAlpine et al. 2006) found that there was a significant increase in the likelihood of koala occupancy in larger patches (>100 hectares). The same study also found that secondary habitat (in addition to primary habitat) was very important for koala survival.

While landscape connectivity datasets can provide indicative measures of the linkage value of habitat within and between sub-populations and local populations, these datasets often neglect to consider barriers (including natural barriers) to koala movement. Without comprehensive mapping of barriers to koala movement, a data-driven assessment of the linkage value of a koala population will be difficult. As woody vegetation cover is a highly measured feature in vegetation science, it provides a useful metric on which to base habitat fragmentation assessments for the koala.

Analysis approach and datasets

The framework for classification of habitat value for each ARKS considers both the overall woody vegetation cover and the distribution of patch size (above and below 100 hectares).

At a population scale, incorporating both patch size and a measure of overall landscape clearing gives a useful measure of the degree of vegetation fragmentation. More highly vegetated and more well-connected landscapes with larger patches are more likely to provide fewer barriers to koala migration and recolonisation after disturbance events. Four classes of habitat fragmentation and clearing have been recognised by the analysis, shown in Table E.4 below.

Table E.4 Habitat fragmentation and clearing value assessment

Value class	Value class description	Value score
High	Vary large areas of contiguous forest and woodland (>300 ha)	1.0
Moderate	Large areas of contiguous forest (>100 ha)	0.75
Low	Fragmented lands (<100 ha)	0.5
Very low	Cleared lands	0.25

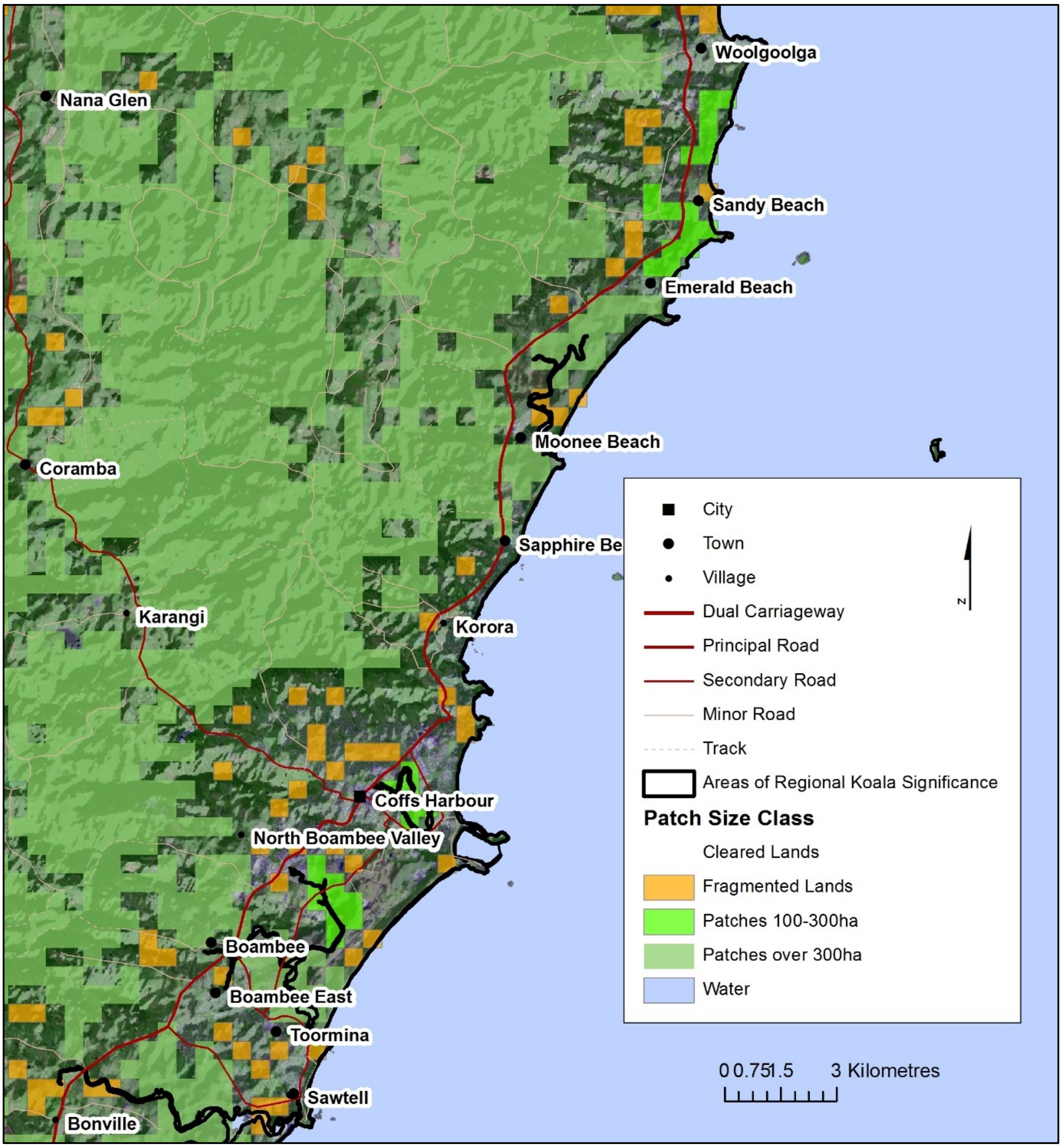


Figure E 2 Landscape consolidation for Coffs Harbour – North Bellingen ARKS

Habitat suitability

Rationale

Koala habitat can be broadly defined as any forest or woodland containing species that are known koala food trees, or shrubland with emergent food trees. The distribution of this habitat is largely influenced by land elevation, annual temperature and rainfall patterns, soil types and the resultant soil moisture availability and fertility. Preferred food and shelter trees are naturally abundant on fertile clay soils (DEE 2017).

Arguably the most important factor influencing koala occurrence is the suite of tree species available (DECC 2008). In any one area, koalas rely on regionally specific primary and/or secondary feed tree species. Where these are scarce or absent, the carrying capacity of the habitat is reduced or eliminated.

Background

The current SEPP44 defines potential habitat as vegetation communities with greater or equal to 15% canopy composition of koala feed trees. This applies to any structural type from woodland to closed forest.

A spatial data audit (Rennison 2017a) identified that reliable habitat suitability mapping is only sporadically available for koala occupied areas of New South Wales. Current mapping programs being undertaken by OEH have the objective of achieving a statewide map by 2019.

Analysis approach and datasets

The only consistent statewide vegetation dataset for New South Wales is *Ocean Shores to Desert Dunes: The Native Vegetation of NSW and the ACT* (Keith 2004). This dataset has a classification resolution of 'Keith class', which provides indicative canopy species and has been sourced from the best available underlying vegetation dataset. The spatial resolution of this map is a 200 metre raster.

Keith classes were grouped into four suitability classes based on the indicative canopy species listed in the profile of the class description (Keith 2004). The regional feed tree species from the koala recovery plan (DECC 2008) were used as a basis for determination. Table E.5 lists the habitat suitability groups determined for the analysis. Figure E.3 illustrates the mapped expression of these suitability classes for the Coffs Harbour area.

Table E.5 Habitat suitability value assessment

Habitat suitability class	Class description	Habitat preference class	Value score
Probable suitable habitat	At least one primary feed tree listed as common in canopy	High	1.0
Possible suitable habitat	One or more secondary feed tree species in canopy and /or primary feed tree listed as occasional	Moderate	0.75
Other native forest or woodland vegetation	No primary or secondary species listed in profile. Native forest or woodland form	Low	0.5
Not native / non-forest vegetation	Non-forest native vegetation or cleared land	Very Low	0.25

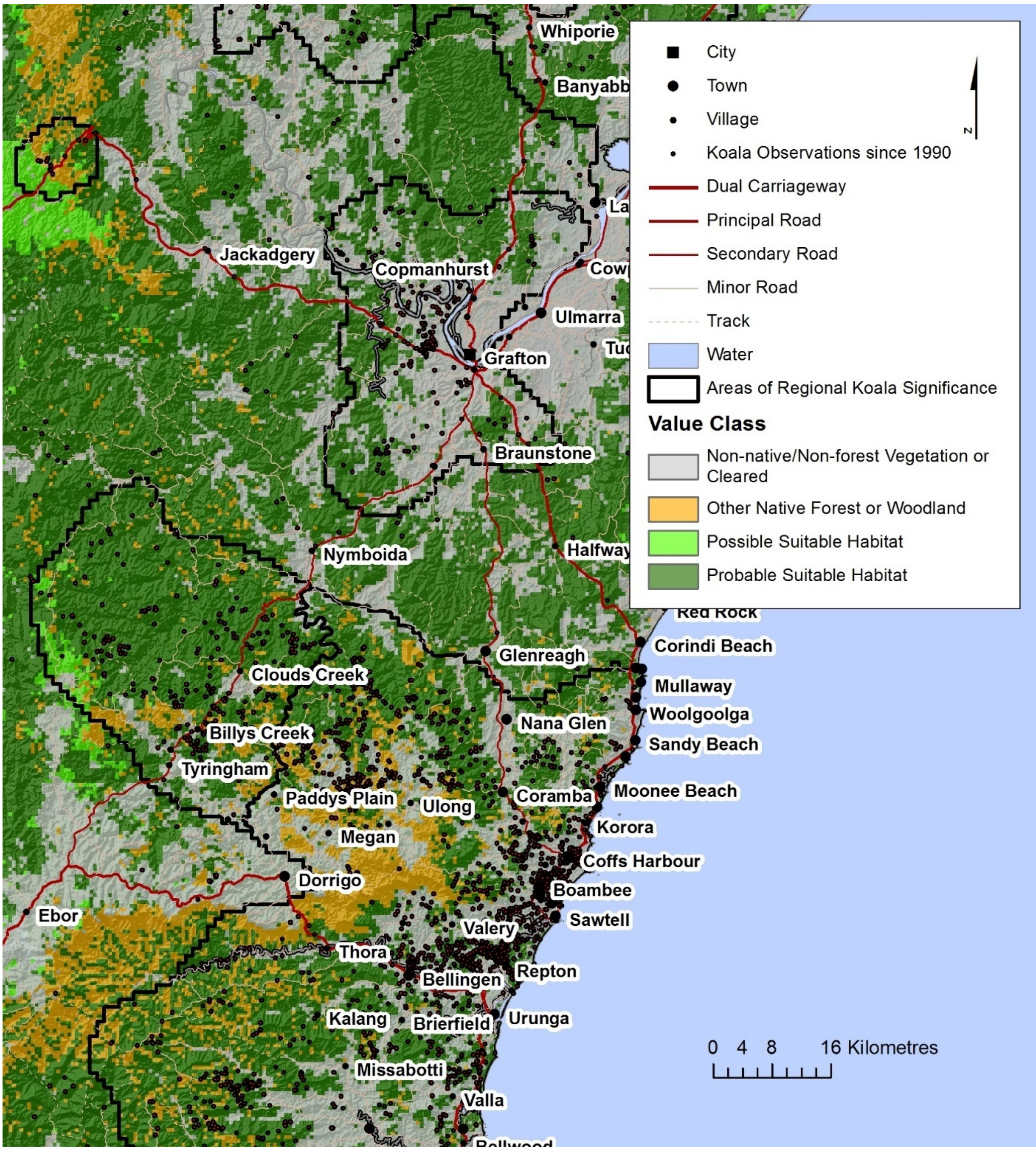


Figure E 3 **Habitat suitability for Coffs Harbour – North Bellingen ARKS**

Riparian refugia

Rationale

Climate change is a potential threat to the koala, as it is expected to lead to increased frequency of high temperatures, changes to rainfall, increasing frequency and intensity of droughts, and increased fire risk over much of the koala’s range (NRMMC 2010). Increased temperatures inland are expected to cause the koala’s range to contract eastward (Adams-Hosking 2011, Adams-Hosking et al. 2011, Dunlop & Brown 2008, Queensland Office of Climate Change 2008, Steffen et al. 2009). This effect would be compounded by extended drought that may be expected under climate change scenarios (Queensland Office of Climate Change 2008). Access to permanent water in times of drought and heat stress is considered an important landscape feature for koala populations during these high stress events.

Background

In the west and north of their range, in Queensland, the distribution of koalas is determined by heat in combination with water availability (Munks et al. 1996, Sullivan et al. 2003). This is reflected in a tendency for the highest densities of koalas to be found along creek lines. Drought may also be a significant factor in the decline in koalas in coastal south-east Queensland (McDonnell 2010), where the substantial decline has largely been attributed to habitat fragmentation, vehicle strike and predation by dogs.

Where droughts are severe there is well documented evidence of the devastating effects on koala populations, with Gordon et al. (1990) reporting a 63% reduction in population numbers during a drought in southern Queensland in the early 1980s. In this case the only animals that survived the severe conditions were those in habitat close to permanent water holes. The defoliation of drought stressed trees resulted in the malnutrition and dehydration of koalas away from the better-quality habitat. In years to follow with good seasons the population did recover and recolonise the area.

Crowther and colleagues suggest that shelter trees are equally important as food trees and should be weighted as such when assessing habitat suitability. Shelter trees play an essential role in thermoregulation and are likely to be selected based on height, canopy cover and elevation (i.e. trees occurring in gullies are preferable) (Crowther et al. 2014). The difficulty regarding shelter trees is that, unlike food trees, there is no identified sub-set of forest and woodland trees known to be shelter trees. The use of a tree species, or individual trees within a species is highly contextual and variable (Crowther et al. 2014).

Analysis approach and datasets

Mapping of permanent water across New South Wales has been undertaken with relative precision within the NSW Digital Terrain Database (DTDB), which denotes feature types as perennial versus ephemeral and natural versus man-made. Using proximity analysis, it has been possible to analyse the proportion of potential habitat within population areas that have access to a permanent water source during times of drought. Population areas with a higher proportion of their habitat area with a permanent water source are predicted to have a higher overall resilience to drought and heat stress. The refugia classification in Table E.6 below ranks population areas based on the proportion of potential habitat within home range distance of mapped permanent water, including perennial streams and natural point source water. Man-made dams have been included in the analysis, as there is evidence that in western areas, koalas can rely on farm dams as a source of water when natural waterways are dry.

Table E.6 Riparian refugia value assessment

Class description	Refugia class	Value score
Large habitat patch (>100 ha) with access to permanent water	High	1.0
Small habitat patch (<100 ha) with access to permanent water	Moderate	0.75
Other habitat without access to permanent water	Low	0.5
Non-habitat lands	Negligible	0.25

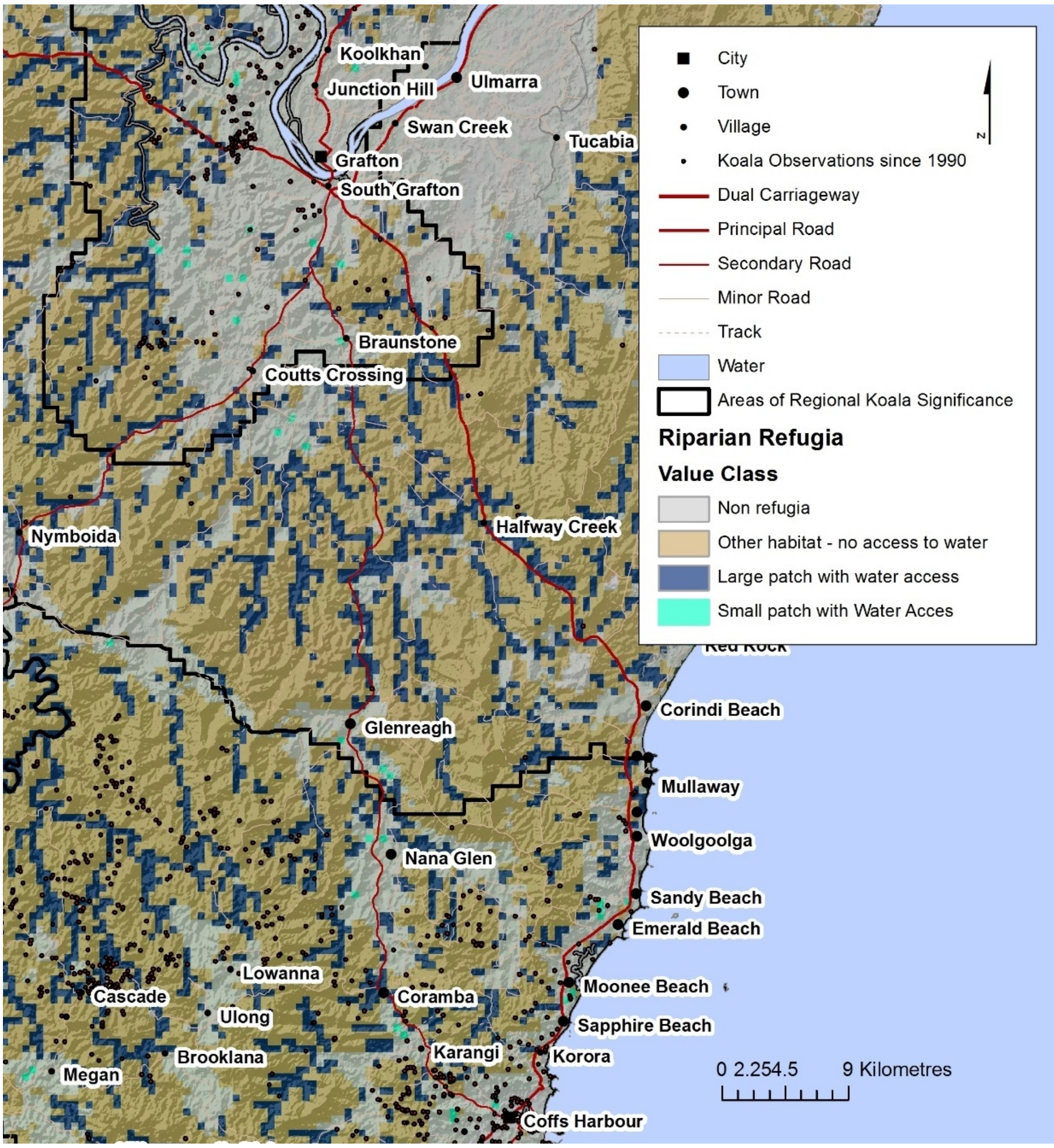


Figure E 4 **Riparian refugia for Coffs Harbour – North Bellingen ARKS**

Koala occupancy

Rationale

Most koala populations in New South Wales now survive in isolated and fragmented habitat, while koalas remain absent from apparently suitable habitat. This phenomenon demonstrates the difficulty in koalas re-colonising areas following local extinction events, particularly in fragmented landscapes (DECC 2008).

The fickle nature of koala distribution patterns in New South Wales highlights the importance of investing significant effort to identify lands currently occupied by koalas, and to focus on the protection of koalas where they reside, rather than protecting habitat as a surrogate for koala occupancy.

Background

The preliminary map of likelihood of koala occurrence in New South Wales (OEH 2015a), although broad, is the only current baseline dataset for koala occupancy for the State that is complete. The dataset contains information relating to both the likelihood of koala occurrence within a 10-kilometre grid (five kilometres on NSW north coast) and the confidence with which that estimate is made. The likelihood map was undertaken with the intention to guide forestry regulation (private native forestry (PNF) Property Vegetation Plans (PVPs)). While the dataset cannot provide definitive guidance at a property level, it can be a useful flag for further investigation or survey.

Analysis approach and datasets

The approach of the value assessment has been to use the probability of occurrence value (p value) in the likelihood of occurrence dataset, grouped into the classes specified in Table E.7 below. Confidence values are also identified in the dataset and, while not contributing to the value score, these will be carried forward to the ARKS profile to provide guidance on the overall confidence measure of the assessment. This approach will provide the map reader with direct guidance on the paucity or otherwise of koala data for any given landscape grid area.

Table E.7 Likelihood of occurrence value assessment

Class description	P value	Value class	Value score
Very high likelihood of occurrence	0.75 – 1	Very High	1
High likelihood of occurrence	0.5 – 0.75	High	0.75
Moderate likelihood of occurrence	0.25 – 0.5	Moderate	0.5
Low likelihood of occurrence	0.05 – 0.25	Low	0.25
Very low likelihood of occurrence	0.00 – 0.05	Very Low	0.05
No evidence of occurrence	N/A	N/A	0.00

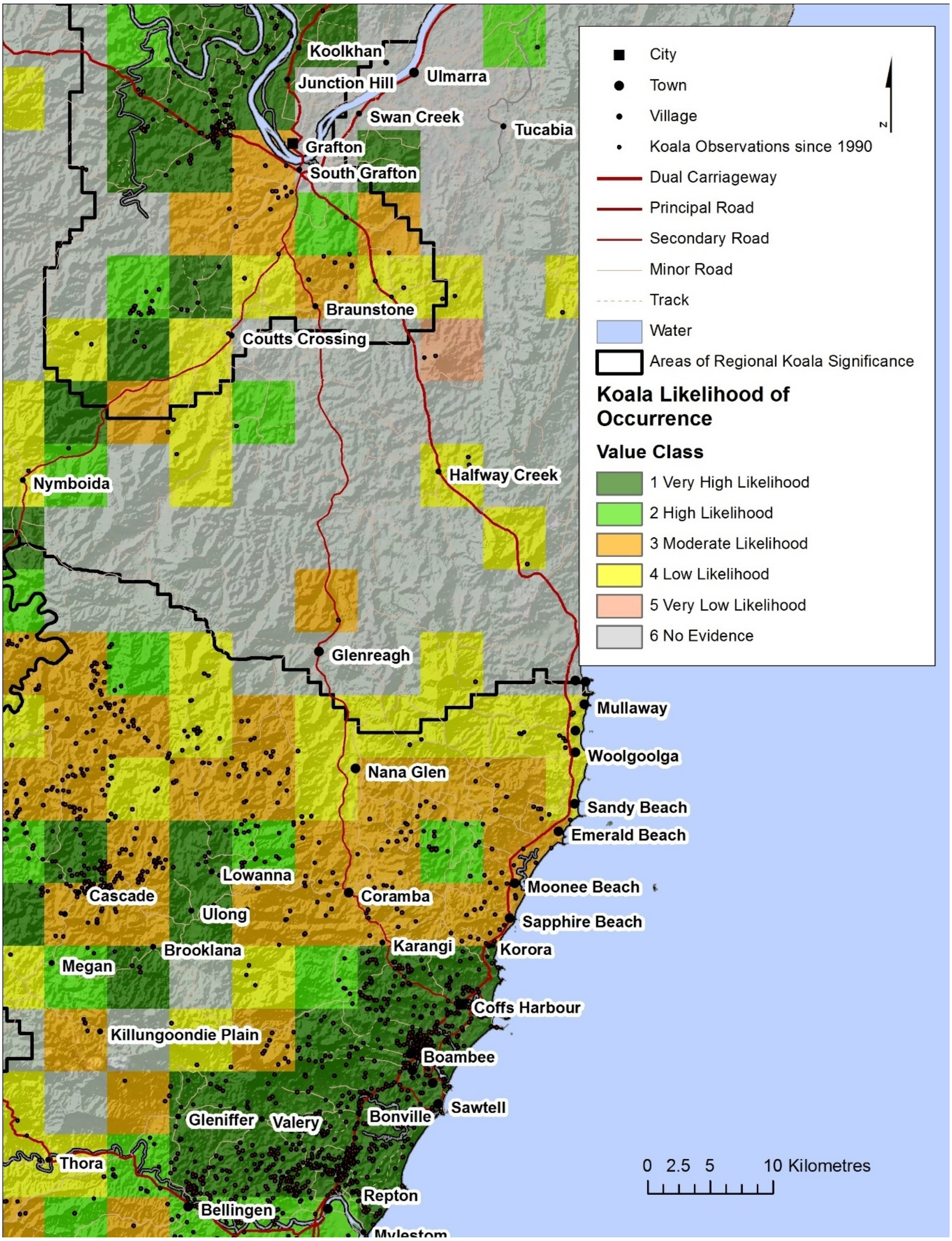


Figure E 5 **Likelihood of occurrence for Coffs Harbour – North Bellingen ARKS**

Values integrity mapping

Background

As a key input into the resilience analysis for ARKS in New South Wales, mapped koala values are compiled using a simple cumulative index to represent their overall relative significance at a regional scale. As with the individual values mapping datasets, the values integrity mapping is represented at a spatial scale of 500 metres (raster) and using an attribute index (0–100) to convey relative cumulative value for each grid square.

The values integrity mapping is designed as a representation of the overall value of land for koalas, independent of any threatening processes that may be active, or have potential to be active, in an area of land.

Analysis approach and datasets

The values integrity mapping is collated from a weighted index of each of the five koala value predictors, rescaled (0–1) and grouped into five classes for display purposes. Each of the five value predictors (forest maturity, patch size, habitat suitability, riparian refugia and koala occupancy) contribute to the index in an additive way. The weightings for each value class are listed under Step 5, *Calculating site scale functional habitat in an ARKS*.

The final map classes for the values categories, including a guiding description for each class, is presented in Table E.8.

Table E.8 Values integrity mapping cumulative index classes

Value integrity class	Value integrity class description	Value integrity score range
Very high	Very high value for koala conservation. Areas of land which are generally structurally intact, within consolidated areas of habitat and which may contain refugia value.	0.85 – 1.0
High	High value for koala conservation. Areas of land which are generally structurally intact and which contain at least two value features at a moderate or high level. These may include refuge areas outside mapped suitable habitat or fragmented suitable habitat.	0.75 – 0.85
Moderate	Moderate value for koala conservation. Areas of land which are generally marginal to high value lands and may be fragmented or of lower habitat suitability. These lands may still present an opportunity for protection or rehabilitation where they are strategically located within linkage areas or form part of a larger network of significant habitat within an important population area.	0.65 – 0.75
Low	Low value for koala conservation. Areas of land which are generally cleared, or if vegetated, are not suitable habitat with little or no evidence of koala occupation.	0.35 – 0.65
Very low	Very low value for koala conservation. Areas of land which are invariably cleared of native vegetation and generally have little or no evidence of koala occupancy.	0.10 – 0.35

Application of mapping

In terms of application in the final resilience profiles, the values integrity mapping has no formal role. It does, however, provide the user with a useful guide to the predicted 'current state' of the landscape for koala values.

While areas with abundant koala records typically have a higher probability of being classed as 'high' or 'very high' values integrity mapping class, landscapes with sparse or absent koala records should be a flag for investigation including field survey, especially where koala populations are known to exist nearby.

Figure E.6 below illustrates an example of the values integrity mapping (Coffs Harbour and Bellingen).

Figure E 6 Values integrity mapping for South Clarence and Coffs Harbour – North Bellingen ARKS

Threats assessment profiles

Habitat loss and fragmentation

Rationale

Koalas face the risk of habitat loss and habitat fragmentation from land use including agricultural activities, mining and timber harvesting. Habitat loss remains the single most prominent threat to the persistence of koala populations across New South Wales (Lunney et al 2000).

Background

Historic land clearing and fragmentation of remaining habitat by roads and infrastructure has reduced the availability and accessibility of habitat. Further, the degradation of habitat through agricultural and forestry practices remains ongoing. While the introduction of the Private Native Forestry code and Local Land Services Amendment Act Native Vegetation Regulation codes have mitigated the loss of broad-scale clearing, the effects of fragmentation and degradation of habitat continue to pose a threat to koala habitat values. The Approved Koala Recovery Plan (DECC 2008), the Species Profile and Threats Database (DEE 2017) and the koala threat mapping report (Smith, Lunney & Moon 2016) all list habitat loss as a threat.

The planned systematic and incremental conversion of natural and rural landscapes to build urban, commercial and industrial estates is a recognised and significant threatening process for koala populations in New South Wales, particularly on the heavily populated eastern seaboard.

The expanding population of major regional centres in New South Wales, outlined by the regional plans (e.g. DPE 2017), has led to future planning for new urban and employment land which may impact on koala populations.

Analysis method

Many datasets have been compiled representing a range of threatening processes across rural and forest landscapes. Each dataset is targeted to represent rural clearing and habitat degradation processes.

Mining and exploration lease information has been extracted from the MinView database (DPE 2018), which logs mining lease and exploration licence details and spatial extent across New South Wales. Active mineral titles and exploration licences are mapped with risk of habitat loss.

The NSW Environment Protection Authority (EPA) provides a database of PNF properties (identified with a centroid). This database has been used to derive a density map of approvals across New South Wales (aggregated to postcode area). The database lists approvals for PNF activities, not documented activation of those approvals. In this respect, the density of approvals reflects future risk of habitat degradation as well as current risk. By way of summary, Table E.9 displays the number of approvals made in New South Wales (to 2015) by bioregion, including the total area and the average approval size. This table draws attention to the high level of interest in PNF in the north-east of the State.

Table E.9 Private native forestry approvals by bioregion and size (2007 to 2015)

IBRA name	Number of approvals	Total area of approvals	Mean approval size (hectares)
Australian Alps	1	2,429	2,429
Brigalow Belt South	38	17,265	454
Cobar Peneplain	15	6,673	445
Darling Riverine Plains	4	713	178
Murray Darling Depression	1	13	13
Nandewar	29	12,665	437
New England Tablelands	142	36,322	256
NSW North Coast	1,465	228,014	156
NSW South Western Slopes	32	3,537	111
Riverina	164	68,686	419
South East Corner	61	6,045	99
South Eastern Highlands	47	13,526	288
South Eastern Queensland	993	152,806	154
Sydney Basin	60	9,516	159

A density analysis of PNF PVP approvals was constructed for New South Wales based on approvals across the State between 2007 and 2015. During this period there were 3052 approvals ranging in size from less than one hectare to over 24,000 hectares. There has been a regional difference in the average size (area) of approvals, with the larger approvals mostly in the west. Using this data, the density of approvals (approvals per square km) was calculated and included as a threat factor in Table E.10.

The Forest Management Zoning System guidelines (State Forests of NSW 2010) clearly identify permissible activities within Forests NSW zoned land. Forest harvesting activities are mitigated in 'localities or habitat of key threatened and sensitive fauna' through tree retention and exclusion areas.

Historical clearing data and land and soil capability data have been used as a predictor of future clearing and habitat degradation trends across New South Wales. While future industry trends and land requirements cannot accurately be predicted, the capability of land to support agricultural pursuits is more consistent. Mitchell landscapes (largely based on geological and landform units) are used as a spatial unit for the likelihood mapping.

The threat likelihood map applies the highest applicable likelihood class for each analysis square, within each priority class. As a rule, conservation estate likelihood has been assigned as priority, followed by public and private land zoning (including state forest) and minerals titles. Private lands activities including PNF and clearing have been calculated only in landscapes where these activities are considered a threat (rural zoned lands). The assessed land criteria, data class, priority ranking and assigned threat category are presented in Table E.10.

Threat likelihood for private rural lands has been derived through a separate index (Table E.11) using a combination of land and soil capability and historical clearing data (SLATS data since 1988). The conversion of these risk factors to risk classes is made in Table E.12.

Table E.10 Habitat loss and degradation risk classes

Criteria	Dataset	Data class	Priority of dataset	Likelihood class
Formal reserve	National park estate, flora reserve	All classes	1	Negligible
Crown reserves and TSRs	DCDB	Crown reserves and TSRs	1	Rare
Commonwealth land	DCDB	Commonwealth controlling authority	2	Rare
Sydney Catchment Authority	Sydney Catchment Authority tenure	All classes	1	Negligible
Private land conservation	Voluntary conservation agreements	All VCAs	1	Negligible
	Property vegetation plan, conservation in perpetuity	PVP database	1	Negligible
	Wildlife refuge	Wildlife refuges – corporate database	1	Rare
	NCT Conservation Covenant	NCT Conservation Covenants – corporate database	1	Negligible
	Indigenous protected area	Indigenous protected areas – corporate database	1	Rare
	Biobanking agreement	Biobanking agreements – corporate database	1	Negligible
Mining and exploration (State Forests of NSW 2010)	Mineral titles and exploration licences	Land identified as being within a current coal, petroleum or mineral title, open cut	2	Likely
		Land identified as being within a current coal, petroleum or mineral title, underground	2	Rare
		Land identified as being within a current assessment lease	2	Possible
		Land for which a mining lease renewal is currently being sought	2	Possible
		Land identified as being within an exploration area	2	Rare
Private native forestry (EPA database) (rural zoned private lands	PNF approvals	High density of approvals (>0.173 approvals per sq. km)	3	Possible
	Land use (ALUM major categories)	Moderate density of approvals (0.07–0.173 approvals per sq. km)	3	Unlikely

Criteria	Dataset	Data class	Priority of dataset	Likelihood class
outside of conservation agreement only, with a land use of grazing or tree and shrub cover)		Low-density of approvals (0.016–0.07 approvals per sq. km)	3	Rare
		Very low density of approvals (<0.016 approvals per sq. km)	3	Rare
State forest logging activity (State Forests of NSW 2010)	SF Forest Management Zones	General logging (FMZ 4)	2	Possible
		Plantation (FMZ 5 & 6)	2	Likely
		Harvesting exclusions & special prescription	2	Rare
		Other	2	Rare
Clearing history (OEH unpublished) (rural zoned private lands outside of conservation agreement only)	SLATS annual clearing data since 1988, analysed against Mitchell landscapes	High	4	Defer to rural lands index
		Moderate	4	Defer to rural lands index
		Low	4	Defer to rural lands index
Urbanisation	LEP zones	Residential	2	Almost certain
		Commercial	2	Almost certain
		Industrial	2	Almost certain
		Large lot residential	2	Likely
		Investigation or regional plan identified future investigation	2	Likely
		Environmental management and conservation	2	Rare
		Other zones	2	Defer to priority 3

Table E.11 Private rural lands – habitat fragmentation index

Criteria	Dataset	Data class	Factor modifier
Land and soil capability	Land and soil capability	Very slight or slight limitations	0.8
		Moderate limitations	0.6
		Moderate – severe limitations	0.4
		Severe limitations	0.2
		Very severe limitations	0.1
		Extremely severe limitations	0.05
Clearing history (OEH unpublished) (rural zoned private lands outside of conservation agreement only)	SLATS annual clearing data since 1988, analysed against Mitchell landscapes	High	0.4
		Moderate	0.2
		Low	0.1
		Very low	0.05

Table E.12 Private rural lands – risk factor to likelihood class conversion

Cumulative risk factor	Likelihood class
0.32 – 0.06	Likely
0.06 – 0.04	Possible
0.04 – 0.02	Unlikely
0.02 – 0.004	Rare
Less than 0.004	Negligible

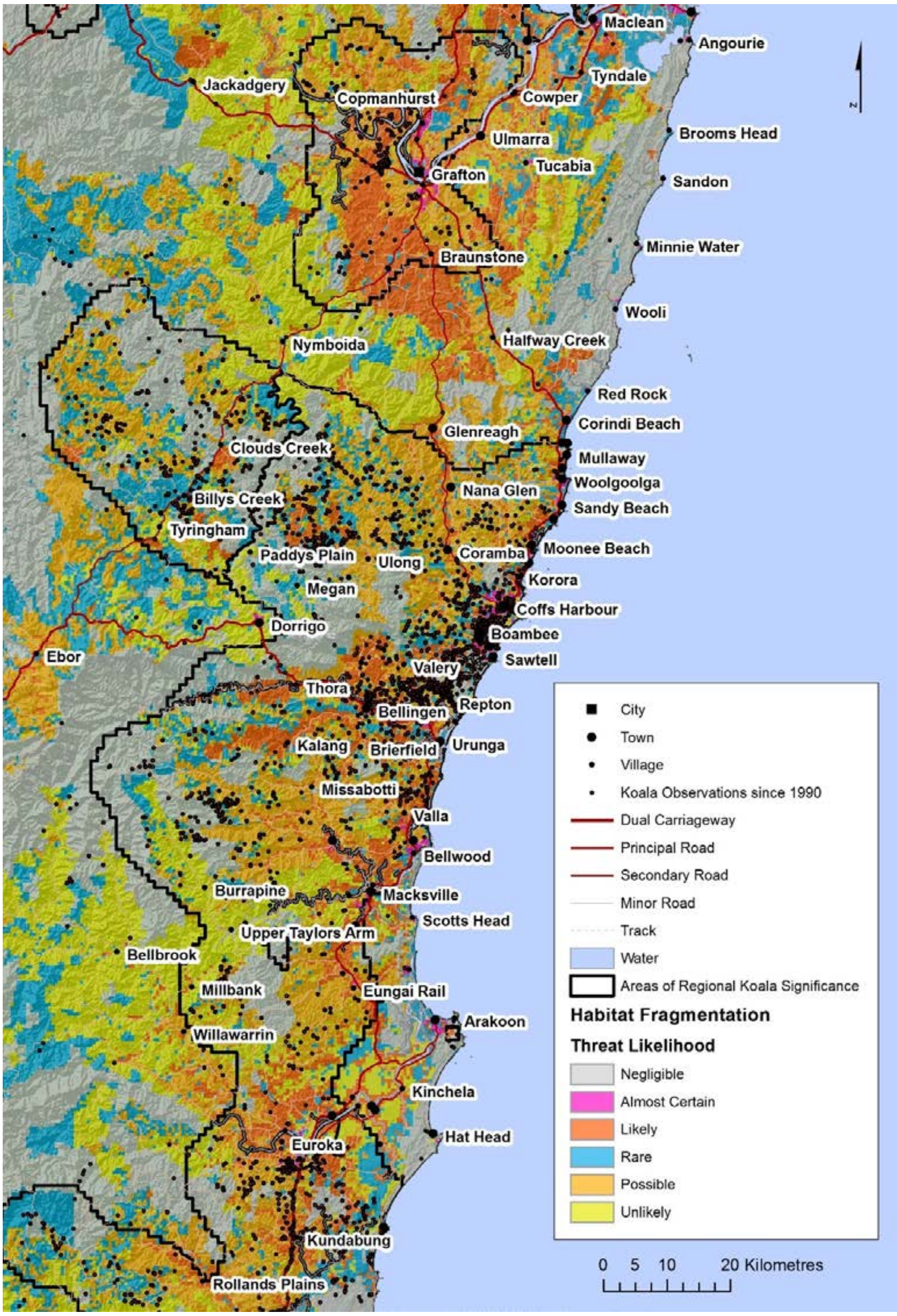


Figure E 7 Habitat fragmentation for north-east New South Wales

Fire – risk of mortality and habitat loss from wildfire or prescribed burns

Rationale

Land use changes and government policy have disrupted the natural fire regimes of many forests, which in turn threaten the long-term viability of remnant koala populations. Fire is essential for the maintenance of koala habitat, and fire exclusion beyond the ecological requirements of vegetation types exacerbates fuel loads, potentially resulting in large high intensity canopy fires leading to irreversible habitat decline and displacement (Andy Baker pers. comm. 2016).

Background

There is some evidence that koalas can survive high intensity fires by seeking refuge in low risk environments such as riparian areas, gorges and rock outcrops prior to fire events (DECC 2008). As an example, Wedderburn Gorge area had very high survival rates from an extremely high intensity summer fire (R Close, University of Western Sydney, pers. comm. 2016). It is postulated that on very hot days koalas leave the trees during the day to take shelter in areas such as the gorge, rocky outcrops, or possibly wombat burrows and other sheltered areas. As a result, when a high intensity fire burnt through this environment later in the day, very few koalas were in micro-environments affected by the fire.

While high intensity fires are accepted to be the highest risk for mortality, frequent low intensity burns are also considered detrimental to koala habitat through the reduction of regeneration of preferred koala feed trees and promotion of species which are more tolerant to frequent fire (DECC 2008).

Analysis method

Two datasets are available which are appropriate for the prediction of high intensity fires:

Fuel load modelling (NSW RFS 2014)

NARCliM Forest Fire Fuel Index (over 50 HFR days per year) (OEH 2016b).

Each of these datasets has been applied as an equal factor in contributing to the overall risk of mortality and reduction in habitat suitability. Typical ranges for fuel loading and Forest Fire Danger Index (FFDI) frequency are given in Table E.13, although actual ranges may vary more widely for a small number of cases.

Table E.13 Fire threat likelihood classes

Fire danger class	Fuel load and FFDI frequency	Fire risk
High	Typically >15 t/ha with a moderate – high frequency of high fire risk days/year (over FFDI 50).	Possible
Moderate	Typically >7 t/ha with a moderate frequency of high fire risk days/year (over FFDI 50).	Unlikely
Low	Typically >5 t/ha with a moderate – low frequency of high fire risk days/year (over FFDI 50). Coastal areas may have higher fuel loads, but with much reduced frequency of high fire risk days/year.	Rare
Very low	Very low fuel loads (typically <5 t/ha) coupled with low risk of high fire danger days/year.	Negligible

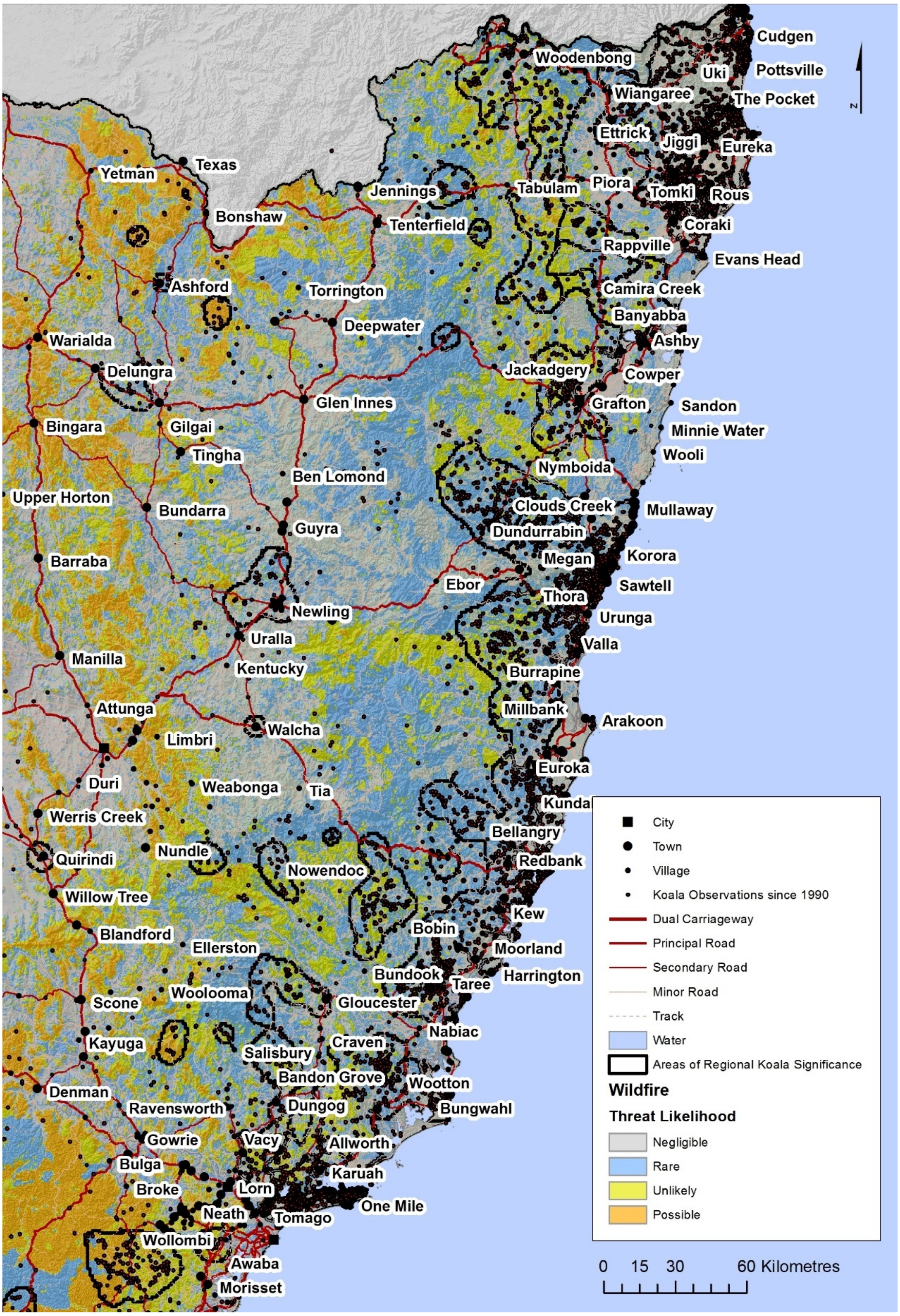


Figure E 8 Wildfire likelihood for north-east New South Wales

Vehicle strike – risk of mortality from collision with motor vehicles

Rationale

Vehicle strike is more likely where roads dissect preferred habitat on flood plain or linkages. This likelihood is exacerbated where habitat and roads correspond with large residential coastal cities and towns and on link roads connecting towns during commuting hours. As urban and peri-urban areas expand into increasingly fragmented historic koala habitat, incidences of mortality from vehicle strike are becoming a more common and influential factor on koala populations. In a study by Dique and colleagues (2003b), koala mortality from vehicle strike was cited as a major factor, with a loss of 5% per annum recorded.

Analysis method

The database of koala observations recorded 545 vehicle strikes between 1990 and 2017. An analysis of the location of these strikes in relation to road type was undertaken across New South Wales. The results of this analysis are presented in Table E.14 below. While urban expansion is a clear threatening process for koalas, the analysis below clearly shows that, per kilometre of road, the primary road class (most rural highways including parts of the pacific highway) is the most likely to cause death or injury to a koala.

Table E.14 Koala observation data – recorded road fatality and injury, 1990–2017

Road_type	Road strikes	Length_m (within PoRS)	Strikes_per_Km (within PoRS)	Relative danger	Likelihood of injury or mortality
Arterial road	123	3,012,920	0.04	Moderate	Possible
Distributor road	3	583,958	0.01	Low	Unlikely
Local road	108	19,727,791	0.01	Low	Unlikely
Motorway	4	307,654	0.01	Low	Unlikely
Primary road	191	1,553,515	0.12	Very high	Likely
r	106	4,141,753	0.03	Low	Unlikely
Track – vehicular	10	40,013,662	0.00	Very low	Negligible

The distance at which roads are no longer considered to influence occupancy viability is determined by the movement characteristics of koalas. A threshold of 300 metres has been set for the maximum distance for the influence of roads, which corresponds with the typical home range movement of a koala in northern coastal NSW (about 20 ha). For the south-east of New South Wales, a wider threshold of 670 metres has been used to accommodate the larger assumed home range movements of animals in these regions.

Figure E 9 **Vehicle strike likelihood for mid-north coast of New South Wales**

Dog attack – risk of mortality from dog attack (wild or domestic)

Rationale

The NSW Koala Recovery Plan (DECC 2008) lists dog attack (wild and domestic) as a significant cause of koala death and injury. The recovery plan considers dogs to be a threat across all koala populations, but particularly in and around urban and peri-urban areas. Between 1997 and May 2011 in south-east Queensland, at least 1144 koalas were killed by dogs (QLD DERM 2011).

Analysis method

Presented in Table E.15, a recent analysis of dog attack data from the NSW Wildlife ATLAS (post 1990) showed that 80% of recorded dog attacks occurred within and around (within 200 m) urban, large lot residential and rural small holdings zoned land. Further, an analysis of dwelling data found that all recorded attacks since 1990 occurred within five kilometres of a mapped dwelling.

Table E.15 ATLAS of NSW Wildlife – recorded dog attacks by land zoning type since 1990

Dog attack category	Number of incidents (since 1990)	% of incidents	Likelihood of dog attack
Dog attack within 200 m of urban and rural residential land	110	80%	Likely
Dog attack outside urban and rural residential land (within 5 km of a dwelling)	27	20%	Possible
Dog attack outside urban and rural residential land (more than 5 km from a dwelling)	0	0%	Rare

Based on this data, threat likelihood classes were mapped according to the proximity to urban lands and rural dwellings. An example of the spatial mapping of these classes in the Coffs Harbour area is shown in Figure D10.

Figure E 10 Dog attack likelihood for Coffs Harbour – North Bellingen ARKS

Disease

Rationale

Chlamydia is the most prevalent koala disease. Although not considered to directly threaten koala populations, where other stressors are high, chlamydia can significantly hamper the health and reproductive ability of the koala population.

Background

Chlamydia is caused by *Chlamydia pecorum* and *C. pneumoniae* (Girjes et al. 1988, Ward 2011). Koalas can have both strains, but those with *C. pecorum* generally show more obvious signs of infection. Symptoms of the infection generally manifest as keratoconjunctivitis (which may cause blindness), respiratory infections, urinary tract infections and reproductive tract infections (Tucker & Wormington 2011).

While chlamydia itself is not considered a threat to overall population survival (Gordon et al. 1990; Reed & Lunney 1990), the combined stress from a range of other threats can trigger chlamydiosis, leading to an overall decline in the health and fecundity of the koala population (Ellis 1997).

Analysis method

The most complete information source for the prevalence of disease in koalas is the collated data from carer groups (OEH unpublished data, 2016). This data collates encounters from 20 groups across New South Wales over a five-year period (2001–2006). The dataset records encounter types including injuries and death from a range of threatening processes. Location information was inconsistently recorded, however the postcode for all encounters was documented. Table E.16 below defines four likelihood classes for disease based on the rate of recorded occurrences of disease across New South Wales, as a fraction of all recorded encounters by care staff. Due to the limitations of care group records, encounters were grouped to the nearest postcode.

Table E.16 Disease likelihood classes

Disease class	Likelihood class
Fewer than five recorded encounters and/or disease encounters made up less than 5% of total encounters	Rare
Disease encounters made up between 5 and 20% of all encounters and the total number of encounters exceeded 5	Unlikely
Disease encounters made up between 20 and 50% of all encounters and the total number of encounters exceeded 5	Possible
Disease encounters made up between 50 and 80% of all encounters and the total number of encounters exceeded 5	Likely

Figure E 11 **Disease likelihood for Coffs Harbour – North Bellingen ARKS**

Heat stress

Rationale

The NSW Koala Recovery Plan (DECC 2008) lists severe weather conditions as drought, heatwave and flood. While floods are not considered a major cause of koala mortality, drought and associated heat stress have been documented as being causes of major mortality events.

Background

Gordon et al (1988) studied a major drought event in south-west Queensland in 1979–80 which led to a crash in the koala population (63% mortality). That study also found that koalas living in areas close to waterholes and streams survived well and koalas living in sub-optimal habitat were the worst affected. Likewise, Ellis et al (2010) concluded that riverine systems provide the highest capacity for conservation of koalas in response to climate change related impacts of heat stress and drought.

Clearing and fragmentation of habitat may also play a role in buffering the effects of drought. Melzer (1994) notes that during a drought in central Queensland (1970–94), adjacent uncleared ranges, which historically supported fewer koalas, did not appear to have suffered the same rates of mortality as riparian refuges in cleared landscapes.

With predictions of future climate change affecting south-east Australia, changes in temperature and moisture availability are likely to lead to a reduction in the suitability of habitat for koalas. A recent study by Briscoe et al. (2016) of climate refugia for the koala suggests a widespread and severe decline in habitat suitability for the koala in large parts of its current range and a contraction to the east and south over the prediction period (models extended to 2070).

To predict the areas of highest impact from climate change, models of predicted change have been utilised. The NSW and ACT Regional Climate Model (NARCliM) is comprised of a 12-model ensemble. The model set includes predictions of seasonal and annual changes to temperature, rainfall and forest fire danger index. The models predict changes over two time periods, 2020–39 and 2060–79.

Koalas exposed to temperatures above 25–30°C regulate their temperature by greatly increasing their evaporative water loss (Briscoe et al. 2014). In addition, by studying koala behaviour during high temperature conditions (above 30°C), it was found that koalas could reduce their body temperature by around 5°C.

Using this data, a temperature threshold of around 35°C would be appropriate to predict heat stress conditions. NARCliM models predict that much of the north-west of New South Wales will experience up to 20 additional days per year of hot (above 35°C) conditions in the period from 2020–39.

Analysis method

The NARCliM predictive model for 2060–79 (days over 35°C) has been used to derive an index of potential risk of heat stress. Although fragmentation and riparian refugia are known to influence heat stress susceptibility, these criteria have been addressed in the *Values analysis* above. Four classes are recognised for the NSW landscape, with a premise of risk increasing commensurately with frequency of extreme heat days. Table E.17 below lists each likelihood class and the predicted frequency of heat stress event days.

Table E.17 Heat stress threat index

Days over 35°C per year (predicted 2060–2079)	Likelihood
0 – 10	Rare
10 – 20	Unlikely
20 – 40	Possible
40 – 61	Likely

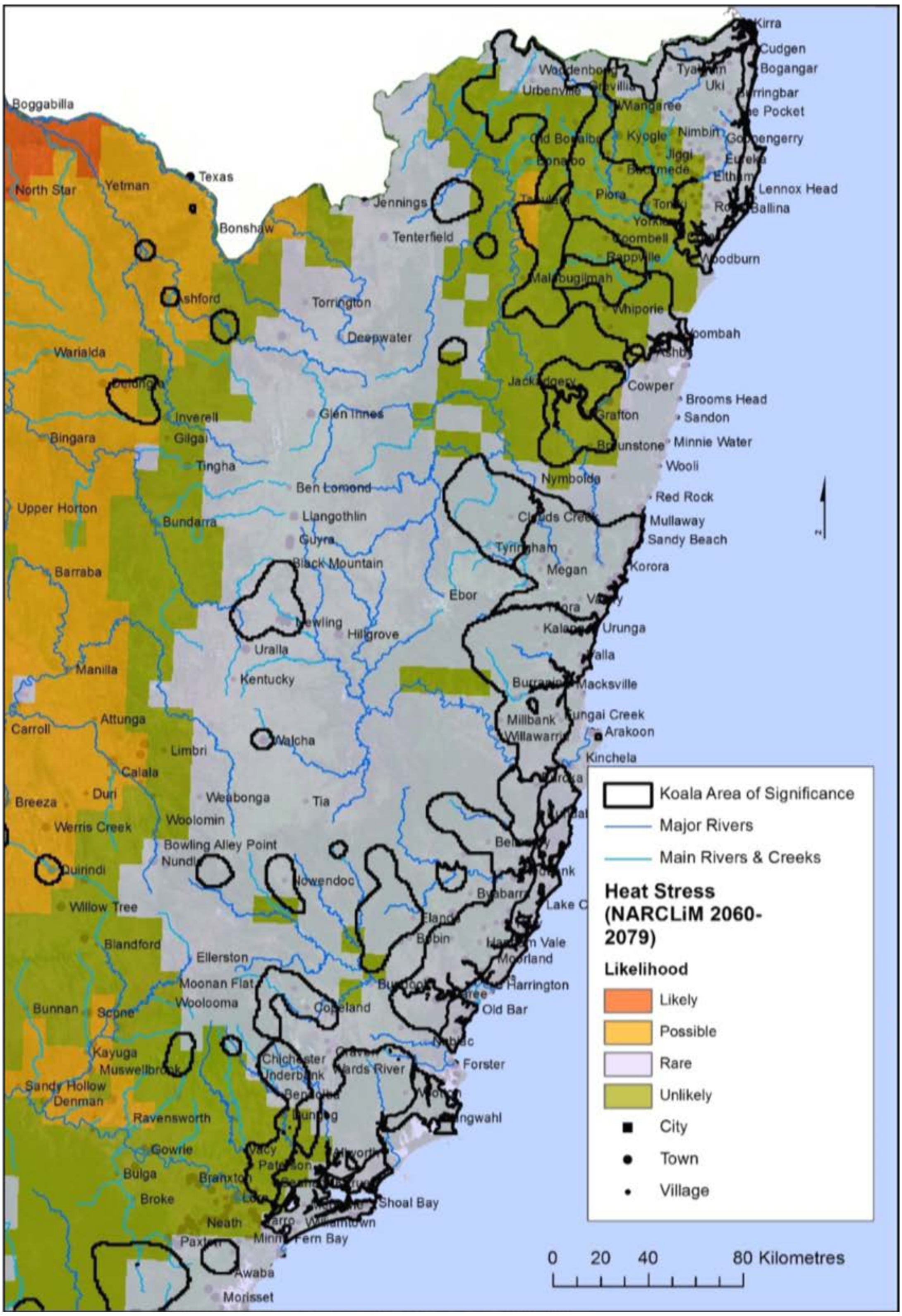


Figure E 12 Heat stress likelihood for eastern New South Wales

Reduction in the suitability of habitat from the effects of climate change

Rationale

The Chief Scientist & Engineer's report into the decline of koala populations (NSW Chief Scientist & Engineer 2016) identifies the cumulative impacts of climate change and interactions with other threats (e.g. fire severity and heat stress) as being potentially severe. Smith, Lunney and Moon (2016) also identified that the threat from fire, drought and heat stress are likely to be exacerbated through the effects of climate change.

A range of other studies have shown that many fauna, including the koala, will be greatly affected in terms of reduction of suitable habitat across their range. Briscoe et al. (2016) used the koala to pilot modelling of the effects of climate change and climate refugia in eastern Australia.

Analysis method

Briscoe identified climate refugia by modelling habitat suitability for reproducing females, because for populations to persist individuals must successfully reproduce. In addition, limitations on lactating females appear to restrict koala distributions in inland and northern areas most likely to be at risk from climate change (Briscoe, *unpublished data*).

A range of predictions were made using Niche Mapper software for current climate and 2070. Yearly maps of habitat suitability (S) were produced, with S calculated as: one minus the proportion of weeks in each year when koalas needed to increase food intake above maintenance levels to meet thermoregulatory costs. It was assumed that koalas ate leaves with average leaf water content (56%), unless they were water stressed when they could seek out leaves with higher water content (66%). If predicted required food intake exceeded the maximum food intake rate recorded for koalas for more than one week, suitability (s) was set at zero (i.e. habitat was classified as unsuitable). It was conservatively assumed that koalas could obtain sufficient free water to balance their water budget (e.g. from wet leaves) if rain in the past week exceeded one millimetre.

Change in suitability from present climate to 2070 was summarised into a five-class likelihood threat surface.

Table E.18 Likelihood of reduction in the suitability of habitat from the effects of climate change

Likelihood of threat	Quantitative range	Description
Rare	0.5980 – –0.1044	No change or positive change to habitat suitability
Unlikely	–0.1044 – –0.2860	Up to 28% increase in weeks per year of water stress
Possible	–0.2860 – –0.4677	Up to 46% increase in weeks per year of water stress
Likely	–0.4677 – –0.6615	Up to 66% increase in weeks per year of water stress
Almost Certain	–0.6615 – –0.9461	Up to 94% increase in weeks per year of water stress

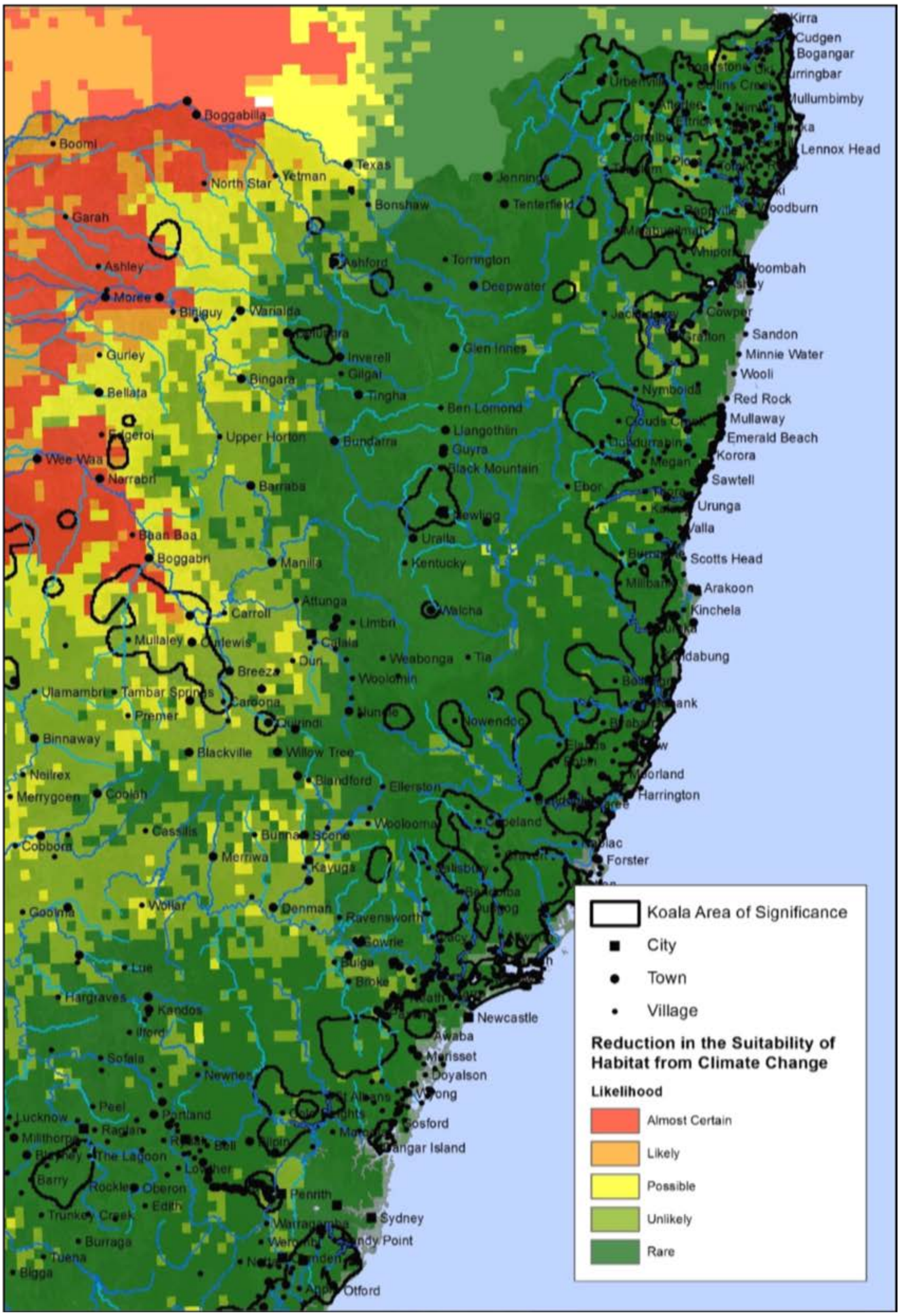


Figure E 13 **Likelihood of reduction in suitability of habitat from climate change – eastern New South Wales**

Glossary

Area of Regional Koala Significance (ARKS)

ARKS are defined as regional scale areas of currently known, moderate to high density of koala occupancy. Spatial ARKS boundaries are based on kernel density analysis of recent koala records (1990–2016). ARKS have been developed for regional scale planning and are regarded as regional koala populations.

Each ARKS map profile contained in Appendix A has been standardised to display a set of key indicators including resilience class, security class, sub-ARKS names (where there are more than one), area, IBRA region and threat risk class. This set of indicators has been brought together for each ARKS to provide all the critical koala information needed for regional koala management.

Values integrity class

The values integrity score provides an overall relative measure of an area's capacity for contributing to koala conservation through habitat values and koala occupancy.

The values integrity mapping is designed as a representation of the overall value of land for koalas, independent of any threatening processes which may be active or have potential to be active.

Values integrity mapping provides an important step in determining resilience of ARKS. The integrity mapping provides a baseline measurement of koala values against which threatening processes are analysed to determine the functionality of habitat.

Threat likelihood class

Threat likelihood is the potential for koala values to be impacted upon across an ARKS and therefore, the likelihood of diminishing habitat integrity and koala viability.

The threat groups identified by this study and others, including the Chief Scientist & Engineer's report (NSW Chief Scientist & Engineer 2016), have been used as a basis for the identification of threats and the development of strategies to spatially define and quantify their influence on koala occupancy and habitat values. Nine distinct threat groupings have been identified for the purposes of this study to provide a framework for the spatial assessment of these threats across population areas in New South Wales.

Threat groups and definitions, the scale of the process at which the threat operates, and the range of koala values impacted directly have been assessed using a matrix to determine the risk and consequence of threats impacting. The scale of determination of threat processes is integral to both strategies for mapping risk and interpreting that risk in a management framework.

It is important to note that the threat maps in the profile show the likelihood of a threat event, not risk, as the risk to each koala value varies with the nominated consequence.

Functional habitat class

Functional habitat is defined as land that is expected to be able to support koala populations into the future, given current assumptions of threatening processes.

For the purposes of calculating resilience at an area scale, only two classes of functionality are recognised. For the purposes of visualisation within profile areas, all four analysis classes are represented on the ARKS profile maps.

Resilience class

The resilience class is a function of the values (habitat and occupancy) and the level of risk they are exposed to by threatening processes.

Resilience is an overall estimate of the likelihood of koalas persisting across a region (averaged for the ARKS) given current and future values and threats.

Resilience, together with security class, are designed to be a surrogate for a viability assessment in lieu of accurate koala population data. As accurate koala population information is not widely available across New South Wales, resilience class is not a measure of population viability; that is, a low resilience class cannot translate directly to mean a 'low viability' population.

The resilience class is an area scale measure of the future predicted ability of koala areas to withstand loss of habitat and occupancy from threatening processes.

Security class

Security class is a function of the koala population's sensitivity to loss and the protection afforded to koalas in an area or region based on tenure (koalas in and outside of lands managed for conservation). Sensitivity to loss has been calculated based on the available functional habitat to support a minimum of 50 breeding females.

Secure areas are deemed to be areas of larger size and landscape functionality, where a higher proportion of koalas are recorded within lands managed for conservation. Low security areas, conversely, are those which are smaller, have a lower overall functionality, and in which a higher proportion of koalas are recorded outside lands managed for conservation.