DEPARTMENT OF PLANNING, INDUSTRY & ENVIRONMENT

NSW Koala Monitoring Framework

A statewide cross-tenure framework to monitor koalas

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Acknowledgements

We thank Nicole Gallahar, Martin Predavec, Ron Avery, David Bain, James Brazill Boast, Steve Cox, Mathew Crowther, Michael Day, Jane DeGabriel, Bob Denholm, Rebecca Gibson, Ron Haering, Damien Higgins, Renae Hockey, Mark Krockenberger, Brad Law, Matt Lott, Daniel Lunney, Heidi Mawbey, Allen McIlwee, David Phalen, Billie Roberts, Ian Shannon, John Turbill, Lachlan Wilmott, Claire Wylie and the Office of the NSW Chief Scientist and Engineer and other Independent Expert Advisory Panel members (Chris Armstrong, Kathy Belov, Carolyn Hogg, Rebecca Johnson and Jonathan Rhodes) for their contributions.

Cover photo: Daniel Lunney/DPIE

Published by:

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ISBN 978 1 922672 07 0
EES 2021/0261
July 2021

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Executive summary

The koala is listed under the *Biodiversity Conservation Act 2016* as a vulnerable species in New South Wales (NSW). Local population trends vary, but reviews indicate that most koala populations in NSW are in decline (McAlpine et al. 2015; Adams-Hosking et al. 2016). This decline was estimated at 26% within the last three koala generations (15–21 years), based on expert opinion (Adams-Hosking et al. 2016). Subsequent to this estimate, the catastrophic 2019–20 bushfire season devastated a significant area of koala habitat. We are yet to fully understand the impact this has had on koala numbers, particularly given that populations had been under stress from ongoing drought conditions since early 2017.

There is a high expectation in the community that this iconic Australian marsupial will be protected in its natural habitat. To help secure koalas in the wild, the NSW Government developed the NSW Koala Strategy in 2018 (the Strategy; Office of Environment and Heritage NSW 2018a). The actions in the Strategy will contribute to the long-term goal of stabilising and then increasing koala numbers, as well as ensuring genetically diverse and viable populations across NSW. One action detailed under the 'building our knowledge' pillar of the Strategy is the development of a statewide, cross-tenure monitoring program in partnership with other agencies, i.e. whole-of-government.

Monitoring plays an important role in the conservation management of threatened species. It is essential to understanding the drivers of decline of a species, evaluating management effectiveness, and providing evidence to support policy (Legge et al. 2018). Long-term data are required to document baselines, detect and evaluate trends in populations, and increase predictive capacity (Legge et al. 2018; Lindenmayer and Likens 2018).

The NSW Koala Monitoring Framework (the Framework) was designed as part of the Strategy, which aims to 'stabilise and then start to increase koala numbers' (Office of Environment and Heritage NSW 2018a). The main way to determine the effectiveness of the Strategy is to monitor koala populations. The Framework provides an overall structure for long-term koala monitoring in NSW. It advocates a consistent, best-practice approach that, if fully implemented, will provide reliable information on population trends and indicators of population health.

The Framework:

- incorporates existing quality monitoring work, where possible
- builds on and synthesises monitoring work to create a complete monitoring program
- recognises the value of the work currently underway and the enhanced outcomes from combining data
- is flexible and adaptable
- fosters collaboration with monitoring partners
- allows a staged approach to monitoring across NSW, which accounts for aspects that can be implemented in the short term and aspects that are more unpredictable and may not be achievable immediately
- sets out goals and procedures for use in negotiation and decision-making to guide a more detailed set of plans and policies, as well as to guide ongoing koala monitoring
- outlines a robust, fit-for-purpose koala monitoring program that the wider community can engage with and use in koala conservation management.

The Framework is designed to facilitate monitoring across six broad functional themes: population dynamics, koala habitat, genetic diversity, disease, reproduction and threats. These should be monitored across the State at a range of spatial scales to give us the best possible understanding of trends in koala populations over time. Effective monitoring of

koalas for population dynamics must occur over multiple koala generations and for long enough to detect trends and gain an understanding of population drivers. The Framework also provides general guidance on monitoring the effect of management/conservation actions targeting threats.

Although this Framework focuses on a 10-year period it is necessary to continue monitoring koalas well beyond this timeframe.

Successful, long-term implementation of the Framework will lead to:

- robust data on the status of koala populations over a time period sufficient to detect trends
- timely warning of koala populations in need of management intervention, resulting in concrete action
- evidence-based information about whether specific management actions are effective tools for koala conservation
- addressing key knowledge gaps, which will enable us to develop management actions that deliver ongoing and effective conservation outcomes for koalas
- informed future policy, programs and decision making that will help achieve the long-term vision of securing koalas in the wild in NSW.

The Framework takes an adaptive monitoring approach to ensure it remains relevant over its lifetime. Specific methods are not prescribed, which enables flexibility when new sites are included and allows transition to new survey technologies that have been demonstrated to be effective through research and validation.

The results from koala monitoring programs under the Framework will feed into the adaptive management process of the NSW Koala Strategy (Office of Environment and Heritage NSW 2018a) and contribute to evaluation of the success of management actions in achieving the objectives of the Strategy. The cyclical nature of this process allows modification of actions if objectives are not being met, to ensure we provide better conservation outcomes for koalas.

Aboriginal acknowledgement

The Department of Planning, Industry & Environment acknowledges the traditional owners of Country throughout Australia, their history and continuing connection to land, waters, and culture. We pay our respects to their elders, past, present, and emerging through engaging in thoughtful and collaborative processes.

As part of the world's oldest living culture, traditional Aboriginal and Torres Strait Islander owners and custodians of the Australian continent and adjacent islands share a unique bond to Country – a bond forged through thousands of years of occupying, managing and travelling across lands and waterways for ceremony, trade and seasonal travel.

In preparing the NSW Koala Monitoring Framework, we acknowledge the more than 60,000 years of continuous Aboriginal connection to the land that makes up NSW.

For traditional owners, Country takes in everything within the physical, cultural and spiritual landscape – landforms, waters, air, trees, rocks, plants, animals, foods, medicines, minerals, stories and special places. It includes traditional law, kinship, cultural practice, knowledge, songs, stories and art, as well as spiritual beings, and people: past, present and future. Aboriginal peoples maintain a core belief that if we care for Country, it will care for us. Conservation practice is inherent within Aboriginal and Torres Strait Islander cultures, and their respective land management practices.

Koalas are of particular significance to certain Aboriginal communities in NSW, many of which have strong ongoing connections to koalas. Koalas can carry special significance in story lines and/or totems, signifying story, place, and kinship responsibilities. In maintaining these cultural links, Aboriginal groups should play an important role in monitoring koala populations in NSW, not only on their own land, but across tenures and into the future.

1. Why monitor koalas?

Monitoring, as an essential ingredient of conservation management, needs to be regarded as indispensable and supported across land managers, policy makers, researchers and funding bodies.
Legge et al. 2019

Monitoring plays an important role in the conservation management of threatened species. It is essential to understanding the drivers of population change of a species, evaluating management effectiveness and providing evidence to support policy (Legge et al. 2018). Long-term data are required to document baselines, detect and evaluate trends in populations and increase predictive capacity (Legge et al. 2018; Lindenmayer and Likens 2018) because interpretations of population trends from short-term monitoring programs, or the initial results of long-term programs, are unreliable due to natural variation in species abundance (Holthausen et al. 2005).

The koala is listed under the *Biodiversity Conservation Act 2016* as a vulnerable species in New South Wales (NSW). Although local population trends vary, reviews of regional population trends indicate that the majority of koala populations within NSW are in decline (McAlpine et al. 2015; Adams-Hosking et al. 2016). This decline was estimated at 26% within the last three koala generations (15–21 years), based on expert opinion (Adams–Hosking et al. 2016). Subsequent to this estimate, the extended 2019–20 bushfire season devastated a significant area of koala habitat and we are yet to fully understand the impact on koala numbers, particularly given populations had already been under stress from ongoing drought conditions since early 2017 (Bureau of Meteorology 2020). The severity of the bushfires was exacerbated by the drought and dry conditions.

1.1 The NSW Koala Strategy

To secure koalas in the wild in the State, the NSW Government has developed the NSW Koala Strategy (the Strategy). The community expects this iconic Australian marsupial to be protected in its natural habitat.

Actions in the Strategy will contribute to the long-term goal of stabilising, and then increasing, koala numbers and ensuring genetically diverse and viable populations across NSW. The Strategy sets out to achieve this goal by delivering actions under four pillars:

- koala habitat conservation
- conservation through community action
- safety and health of koala populations
- building our knowledge (Figure 1; Office of Environment and Heritage NSW 2018a).

Figure 1 The four pillars of the Strategy

1.1.1 Monitoring in the Strategy

One action detailed under the 'building our knowledge' pillar of the Strategy (Office of Environment and Heritage NSW 2018a) is the development of a statewide, cross-tenure monitoring program in partnership with other agencies.

The NSW Koala Monitoring Framework (the Framework) has been designed as part of the Strategy, the broad objective of which is to 'stabilise and then start to increase koala numbers' (Office of Environment and Heritage NSW 2018a).

The primary way to determine the ultimate effectiveness of the Strategy is to monitor koala populations. Koala monitoring across NSW plays multiple roles in achieving the goals of the Strategy, including:

- detecting trends in populations and indicators of population health (genetic diversity, disease and reproduction), which will trigger effective and timely responses
- assessing changes in the extent and quality of habitat and the impact of threats to koalas
- determining whether conservation actions related to koalas, such as local community actions and fauna rehabilitation work, are influencing their populations
- contributing to the overall evaluation of the Strategy.

The results from koala monitoring programs under the Framework will feed into the adaptive management process of the Strategy (Office of Environment and Heritage NSW 2018a) and contribute to evaluation of the success of management actions in achieving the objectives of the Strategy. The cyclical nature of this process allows modification of actions if objectives are not being met, so that they provide better conservation outcomes for koalas.

1.2 The NSW Koala Monitoring Framework

The Framework has been developed to provide an overall structure for long-term koala monitoring in NSW. It advocates a consistent, best-practice approach that, if fully implemented, will provide reliable information on population trends and indicators of population health. These trends will indicate whether the goal of the Strategy – to stabilise and increase koala numbers – is being achieved and whether the management actions targeting threats are effective or need to be modified as part of the adaptive management approach of the Strategy.

The Framework is based on the concept of incorporating existing monitoring work where possible and then building on and synthesising that work to create a complete monitoring program. This recognises the value of the work currently underway as well as the potential gained from combining these data. The Framework is flexible, adaptable, and fosters collaboration with monitoring partners. It allows a staged approach to monitoring across the state, which accounts for aspects that we are confident we can implement now and aspects that are more unpredictable and may not be achievable immediately. The Framework sets out goals and procedures for use in negotiation and decision-making to guide a more detailed set of plans and policies, as well as ongoing koala monitoring. Importantly, it sets the bar high by outlining a robust, fit-for-purpose koala monitoring program that the wider community can engage with and use in koala conservation management.

1.2.2 Objectives of the Framework

The primary objectives of the Framework are to:

- provide robust data on the status of koala populations across NSW over a time-period sufficient to detect trends (at least 10 years)
- provide timely warning of koala populations that need management intervention, which leads to concrete action to reduce threats
- determine whether specific management actions are effective tools for koala conservation
- address key knowledge gaps to develop management actions that deliver ongoing and effective conservation outcomes for koalas
- inform future policy, programs and decisions that will help achieve the long-term vision of securing koalas in the wild.

Specific scientific objectives, SMART (specific, measurable, achievable, relevant and time-bound) sampling objectives and decision triggers are outlined in each section of the Framework. If changes detailed in the sampling objectives are detected, action follows. The data evaluation sections indicate the frequency of assessing data against the sampling objectives and decision triggers. Further details of this process are given in section 10.4.

The Framework takes an adaptive approach, allowing for changes in design and methods used, as a more comprehensive understanding of koala population trends over time is developed. It necessitates a range of methods and collaboration with different agencies and sectors of the community.

1.2.3 What the Framework doesn't do

There are several things that the Framework doesn't do. It does not:

- set strict requirements for survey design and methods across all spatial scales. There are many different situations when koalas must be monitored – and many different survey/monitoring methods may be used. The emphasis is on ensuring that core data are collected regardless of the methods used
- use the koala as an indicator species. The monitoring relates only to koalas and the data to be collected are not necessarily measures of general environmental health
- monitor koalas outside NSW. There will be consultation with bordering states as well as the Australian Government where required
- monitor captive populations of koalas. Koalas in zoos that are accredited by the Zoo and Aquarium Association are monitored across Australia by the Australasian Species Management Program
- monitor progress in implementing the Strategy (i.e. procedural). There is a separate program of monitoring, evaluation and reporting implemented as part of the Strategy.

1.2.4 Timeframe

Effective monitoring of koalas must occur over multiple koala generations and for long enough to detect trends. Although this Framework focuses on 10 years, the minimum period considered to be long-term monitoring by Lindenmayer and Likens (2018), we will need to continue monitoring koalas well past this timeframe to gain an understanding of:

- their response to changes in habitat (losses from land use changes and gains from conservation actions)
- their resilience to extreme events (e.g. fire and drought)

- their ability to persist in the face of changing climate
- the effectiveness of management actions.

1.2.5 Review and evaluation

Koala monitoring under the Framework will be reviewed and evaluated every 3 years by the NSW Koala Monitoring Expert Panel and all agencies involved in implementing the Framework, following the 'framework for evaluating the adequacy of monitoring programs for threatened species' (Woinarski 2018). This framework considers nine evaluation metrics: fit-for-purpose, coverage, sampling periodicity, longevity, design quality, coordination, data availability and reporting, management linkage and demographic parameters. Full details of the evaluation process, including an initial evaluation of koala monitoring with the Framework, are provided in section 10.5.

2. The monitoring framework

The overall regional trend in NSW is a decline in koala populations (McAlpine et al. 2015; Adams-Hosking et al. 2016). However, local population trends vary:

- the Coffs Harbour population is considered stable to slowly declining (Lunney et al. 2016a)
- the Pilliga, Liverpool Plains and Gunnedah populations show rapid decline (Lunney et al. 2012, 2017)
- the Campbelltown population is stable to increasing (Close et al. 2017)
- the South Coast population is significantly reduced (Lunney et al. 2014).

Furthermore, the 2019–20 bushfires impacted koala populations in different ways, depending on fire extent and severity at different locations. Thus, we cannot assume that statewide or regional trends are applicable to individual populations, or that trends at one site can be extrapolated to larger spatial scales (Predavec 2016).

The Koala Monitoring Framework (the Framework) is designed to facilitate and coordinate monitoring across a range of spatial scales (e.g. local, regional, statewide) to give us the best possible understanding of trends in koala populations and indicators of population health over time. Six broad biological/ecological factors need to be monitored: population dynamics, koala habitat, genetic diversity, disease and reproduction, and threats using a range of different methods (Table 1). Details of these factors are provided in subsequent sections.

The Framework also provides general guidance on monitoring the effect of management/conservation actions. It is important to note that monitoring data from different spatial scales are not mutually exclusive. For example, local-scale data on population and disease trends can be extracted from the statewide community wildlife survey as well as local-scale site monitoring.

Table 1: An overview of the NSW Koala Monitoring Framework

Metric (section)	Example question(s)	Spatial scale	Possible methods	Suggested frequency
Population dynamics (section 3)	• How do population trends at statewide, regional and local scales vary over time? • How does the spatial distribution/range of koalas change over time?	Statewide/regional/local	Community survey (crowd-sourced data) Community survey (community wisdom)	Every 5 years
		Local	A range of methods, including: • spotlighting transects for relative density • scat surveys for occupancy	Every 1–5 years
Koala habitat (section 4)	• What is the extent and location of change (loss or creation) of potential and known koala habitat over time? What is the nature of this lost or created habitat?	Statewide/regional	Spatial information from the Koala Habitat Information Base (e.g. the Koala Habitat Suitability Model) combined with the yearly Statewide Landcover and Tree Study (SLATS)	Every year
Genetic diversity and functional genetic diversity (section 5)	• How do population connectivity, genetic diversity, boundaries between or within populations and genetic relatedness vary over space and time?	Statewide/regional	Koala rehabilitation and mortality samples Koala capture	Every 3–7 years
Disease and reproduction (section 6)	• How do koala disease and reproduction vary spatially and temporally across the State?	Statewide/regional	Community survey (community wisdom)	Every 5 years
	• How do disease and reproduction vary at the local scale over time?	Local	Koala rehabilitation and mortality records and samples	Every year
			Scat surveys	Every 1–5 years
			Koala capture	Periodically
			Spotlighting surveys	Every 1–10 years

Threats (section 7)	• How does the relative intensity of threats vary spatially and temporally statewide?	Statewide/regional	Community survey (community wisdom)	Every 5 years
	• How does the relative proportion of threats change over time at the local scale?	Local/regional	Koala hospital and rehabilitation and mortality records	Every year
Effectiveness of local projects/actions targeting threats (including research projects and management actions; section 9)	• Have specific management/conservation actions been successful? (e.g. specific actions funded under the *Saving our Species* Iconic Koala Project or the NSW Koala Strategy)	Specific to action/project	Determined on a project basis	Determined on a project basis

The Framework is a dynamic document that will follow the process of adaptive monitoring (Box 1). Data evaluation points are given in each section of the Framework. These regular points are the stage at which the data is evaluated against sampling objectives, and the point in the adaptive monitoring process where questions, protocols and methods are assessed and can be changed (see overview in section 10.4). Throughout the Framework, reference is made to potential points at which change may be considered; for example, questions may change if new technology enhances data collection (section 3.3.2) or there may be modifications to frequency of data collection if rates of population change are different to expected or vary over time (sections 3.3.2 and 5.3.2).

Box 1: Adaptive monitoring

'An adaptive monitoring framework enables monitoring programs to evolve iteratively as new information emerges and research questions change' (Lindenmayer and Likens 2009)

Many monitoring programs have been ineffective due to a lack of well-formulated questions, poor design and debates about what to monitor. In contrast, successful monitoring has well-designed questions, rigorous design, a conceptual model and a reason for monitoring that is relevant to management and conservation of wildlife or resources (Lindenmayer and Likens 2009).

Based on their review of the shortcomings of many monitoring programs and the characteristics of effective programs, Lindenmayer and Likens (2009) proposed 'adaptive monitoring', which provides a framework in which setting questions, design, data collection, analysis and interpretation are iterative steps. This approach allows the monitoring program to change if new information leads to new questions, a new analytic approach, or if new technology enables more effective data collection. Changes to the monitoring program must be considered carefully so that the usefulness of the long-term data set is not diminished by adopting new techniques or technological advances. Successful implementation of an adaptive monitoring approach should make programs more credible to the scientific community, enable greater relevance to management and facilitate effective use of public money (Lindenmayer and Likens 2009).

Since the introduction of adaptive monitoring, case studies have been examined to provide 'proof of concept' of the framework (Lindenmayer et al. 2011). Furthermore, strategic adaptive monitoring has been developed. This is a staged, pragmatic approach to monitoring, which first establishes a reference baseline, and is then followed by a reduced monitoring effort to focus on priority areas (Wayne 2018). Adaptive monitoring is relevant to many kinds of monitoring, but it is not a prescriptive framework. Its application depends on the specific circumstances and context of the program and issues that arise throughout its lifetime (Lindenmayer and Likens 2018).

Adaptive monitoring shares some similarities in approach to adaptive management. Broadly, adaptive management involves improving management of a species by learning from the outcomes of management actions and introducing interventions where required. The approach varies, but includes similar key steps: setting goals/objectives, development of a conceptual model, planning and implementing management actions and carrying out monitoring (at small or more general scales), evaluating the success of management with respect to the objectives and updating the above steps as required (Lindenmayer 2018; Office of Environment and Heritage NSW 2018b).

Adaptive monitoring has been adopted by the NSW Koala Monitoring Framework and the monitoring data generated feeds into the adaptive management process of the NSW Koala Strategy (Office of Environment and Heritage NSW 2018a).

The Framework is based on the premise that significant work is already underway to collect data on koala populations across NSW. For example, the *Saving Our Species* Iconic Koala Project 2017–21 (Office of Environment and Heritage NSW 2017), the Coastal Integrated Forestry Operations Approval Proposed Monitoring Plan 2019–2024 (Natural Resources Commission 2019a) and the NSW Forest Monitoring and Improvement Program (Natural Resources Commission 2019b). Rather than duplicate or attempt to replace this work, the Framework focuses on incorporating and building on and synthesising this work. It recognises the important contribution that many groups have made (and will make) to our knowledge of koala populations, and that ongoing work and contributions are vital for the successful monitoring of koalas.

In developing the Framework, we recognise that some elements of the Framework are already underway and locked into place, such as the Koala Habitat Information Base, which is an action under the NSW Koala Strategy. In these cases, we have included details of the elements in the Framework. In other cases, specific elements will need to be confirmed and refined as the Framework is implemented. In these cases, the information included in the Framework is more general in nature.

For example, we are engaging with and learning from Aboriginal communities about traditional knowledge relating to koalas and their habitat. Our Indigenous partners will be supported to monitor koalas on their land and across tenures. An example of Indigenous biocultural monitoring is given in Box 2.

Box 2: Good Gumbaynggirr Koala Country Plan – Indigenous biocultural monitoring

Aboriginal people monitor seasonal and cyclical changes in animals and plants and how they interact within the landscape. Biocultural monitoring relates to relationships between nature and culture, and between biodiversity and heritage. It is the cultural response to biodiversity monitoring and involves caring for and responding to biodiversity on Country using indicators based on traditional ecological knowledge (TEK).

Gumbaynggirr Darruyay Dunggirr Jagun Mangga-Bayilaygam (The Good Gumbaynggirr Koala Country Plan) offers an outstanding example of using TEK to develop management and monitoring approaches for the koala in northern NSW. The project uses the Gumbaynggirr koala creation story, that tells of Dungirr gagu (koala brothers) and sea level rise and is a reminder, a warning and a solution to changes in the landscape, now accelerated due to climate change. This project has a strong focus on cultural protocol and law that protects Dungirr (koalas), a cultural keystone species, and their habitats, alongside other important cultural species such as whale and quoll. Cultural knowledge workshops held on Country determined how Indigenous knowledge and practices should be used to manage Country for the benefit of the koala. The project primarily uses biocultural monitoring, along with western scientific methods to monitor the implementation of the plan and to enhance and protect the biodiversity on their Jagun (Country).

In the past, Gumbaynggirr people directly observed koala behaviour using sight, sounds and signs. They now use additional methods such as camera traps and heat-sensing drones. They also use seasonal calendars to determine management actions, and collect and pass on information about koala behaviour and other important cultural species to the next generation.

Gumbaynggirr koala monitoring also uses photo points, camera traps and plant surveys to monitor the impact of climate change and wildfire on cultural places and koala movement. These impacts affect traditional resources, knowledge of Jagun and cultural attachment to species (totems, foods, medicines and cultural practice), and also restrict where koalas can live.

For other examples of partnerships between an Aboriginal communities and the NSW Government, visit the NSW Koala Country website: https://koala.nsw.gov.au/culture/.

3. Population dynamics

Regular, systematic monitoring of koala populations will help us understand the patterns of population change, inform appropriate interventions, and allow success to be identified.
NSW Chief Scientist and Engineer 2016

In areas where populations have been monitored over repeated periods, a variety of trends have been found (Lunney et al. 2016a, 2017; NSW Chief Scientist & Engineer 2016). This indicates that:

- we cannot consider koalas as a single population in NSW
- focusing solely on statewide trends in koala populations may be misleading (Predavec 2016).

Therefore, koala population trends need to be monitored at a range of scales, from statewide to local, in cross-tenure urban, peri-urban and rural areas as well as native forest (state forests, national parks, private native forests and Crown forested land).

Snapshot 1: The declining koalas in the Pilliga forests

In the 1990s, the Pilliga forests had the largest population of koalas west of the Great Dividing Range. By 2007, anecdotal evidence suggested that the population was declining. To assess this concerning trend, Lunney et al. (2017) resurveyed sites that were sampled between 1991 and 2011 using scat and canopy searches.

What did they find?

They found that there had been a 5-fold drop in occupancy in less than two decades. Furthermore, there was a reduction in activity levels across the sites – 38% of trees had koala scats under them in the initial surveys, but scats were found under only 5% of trees in the repeat surveys. Declines occurred evenly across the Pilliga, with persistence at a site seemingly related to a high initial density of koalas rather than to a slower rate of decline. Sites where koalas persisted were characterised as having higher temperatures and lower rainfall relative to other sites, being close to drainage lines with deeper soils and having a lower occurrence of fire. This pattern fits with the observation in the recent surveys that koalas were next to drainage lines in the western half of the Pilliga and fits with the suggestion that koalas show refugial persistence.

3.1 Objectives

The objective of long-term population monitoring is to determine:

- population trends at statewide, regional and local scales over time
- changes in the spatial distribution/range of koalas over time.

3.2 Survey design overview

Under the Koala Monitoring Framework (the Framework), population dynamics are monitored using a citizen science approach (a statewide community wildlife survey) and through collaborations with agencies and others that monitor koalas at local sites. A community wildlife survey provides a picture of trends at statewide, regional and local scales, as well as community perceptions of population trends. Data collected from koala populations at the local scale provide more detailed information and inform targeted, site-specific management approaches. Table 2 gives a summary of the information we need to collect to monitor trends in koala populations.

Table 2: Koala population monitoring design

Scale	What are the sampling objectives? A decision trigger is activated if there is:	What data do we want?	Example methods	Initial frequency
Statewide/regional/ local	A 20%[1] change in the population of koalas at the regional or statewide level between surveys	Relative abundance	Community survey (crowd-sourced data)	Every 5 years
	A 20% change in the community's perceptions of population trends between surveys	Distribution of responses	Community survey (community wisdom)	
Local	A 20% change in occupancy or density of koalas at a site, with a 95% significance level and 80% power, between sampling intervals	Occupancy Relative density	RGB–SAT survey Spotlighting Acoustic surveys Detection dogs	Every year at smaller sites and every 3–5 years at landscape or local government area scale (McAlpine et al. 2007)

Notes: [1] A decrease of five percentage points (representing a 20% decline) in the proportion of wildlife records that were koalas from the 2006 (25%) to the 2015 (20%) survey was detected in the north-west of NSW (Predavec et al. 2018); RGB–SAT = regularised grid-based spot assessment technique for scat surveys (Phillips and Callaghan 2011).

3.3 Survey methods and analysis

3.3.1 Community wildlife surveys

'Citizen science surveys allow data to be gathered cost-effectively over a long period of time and across a large geographical area, including private land.'

(NSW Chief Scientist & Engineer 2016)

The potential citizen science projects have for collecting data at wide spatial scales, at numerous locations, and on a range of land tenures (including private land, which is often difficult to access) is becoming increasingly recognised. Citizen science has been used to detect spatial and temporal trends in koala populations over time (Brown et al. 2018; Predavec et al. 2018; Dissanayake et al. 2019), model habitat use (Crowther et al. 2009),

predict habitat suitability (Sequeira et al. 2014) and engage the community in koala management policy (Hollow et al. 2015).

A community wildlife survey incorporating citizen science is used in the Framework to determine the presence or absence of koalas at the statewide scale as well as the community's perceptions of change in koala populations and their threats over time. Comparison with the results of a similar survey undertaken in 2006 will allow changes in the distribution and population trends to be identified.

Location

A community wildlife survey is statewide.

Timeframe and repeat survey

The survey should be repeated every 5 years.

Methods

The survey was designed by the Science, Economics and Insights Division, NSW Department of Planning, Industry and Environment. Using a citizen science approach gives local communities the opportunity to be involved in data collection in their area, thus engaging and educating the community in the monitoring process.

The 2019–21 survey used similar methods to the 2006 survey (Lunney et al. 2009). A web-based format was used instead of a paper-based mapping format, as for the 2015 citizen science survey of the north-west region of NSW (Predavec et al. 2018). The 2019–21 survey was designed to obtain spatially explicit data on the presence or absence of koalas across NSW. In brief, an online survey of people living in NSW was used to obtain animal-sighting data over the past 2 years to enable us to establish presence or absence and relative abundance of 10 widely recognised species, including the koala, at a local level. The survey also asked respondents for their perceptions of whether populations had increased, decreased or stayed the same. In addition, for koalas, it asked about indicators of population health (health and reproduction) and perceived threats (see sections 6 and 7).

Community surveys are most likely to provide robust data in areas where people (the community) are most active (i.e. populated and human-modified areas (Lunney et al. 2016a)). These areas are also where the combined threats to koala populations are likely to be greatest, and where most management is needed.

As with all survey methods, community surveys result in biased data; for example, findings are skewed toward koalas in populated locations (Dique et al. 2004; Dissanayake et al. 2019), responses are influenced by the age, gender and length of residency of respondents (Predavec et al. 2016), and there can be changes in community reporting behaviour over time (Dissanayake et al. 2019). These biases have been addressed in past and current surveys by using robust survey design, keeping methods consistent among surveys, collecting data on koala absence and survey effort, and including measures of confidence in data analysis (Predavec et al. 2016, 2018).

Analysis

A statewide community koala survey was undertaken in NSW during 1986–87 (Reed et al. 1990), in 2006 (Lunney et al. 2009) and again in 2019–21. Future community wildlife surveys will build on findings from these earlier community surveys and allow us to compare wildlife populations across surveys, in particular focussing on comparisons with the 2006 survey.

The results of future surveys will be compared to the results of the 2006 survey to identify areas that report an increase or decrease in the relative density of koala sightings. Details of the analysis methods are given in Predavec et al. (2018). The respondents' perceptions of change in the koala populations will also be assessed as per previous surveys (Predavec et al. 2016, 2018).

Snapshot 2: The value of community wisdom

In 2006, as part of a statewide community survey, community members were asked whether they thought local koala populations were increasing, decreasing, or staying the same. The aim was to examine whether community wisdom could inform conservation.

What did they find?

The results showed that population trends identified through community wisdom were similar to the trends identified by traditional research and monitoring (Predavec et al. 2016). The community wisdom surveys, however, allowed the question to be addressed at much broader geographical scales and time frames.

The surveys also engaged a broad section of the community in conservation research and education.

3.3.2 Local-scale monitoring

At the local scale, the Framework advocates building on, and collaborating with, existing koala monitoring across NSW. This makes the best use of local knowledge, expertise, monitoring history and community support, and recognises that one size does not fit all in a koala monitoring program. This approach ensures that the most appropriate methods are used at each site. It is also the approach most likely to ensure ongoing, long-term monitoring.

To ensure full coverage across the state, some new monitoring sites may need to be established. Sites at the local scale will range from:

- areas within a local government area (LGA), such as a rural property or coastline (about 2000–10,000 hectares)
- an entire LGA or joint organisations of councils appropriate to the location, land-use types, landscape features and management requirements.

Under the Framework, we will work with teams at local sites to ensure that survey designs have sufficient power to detect change in koala populations and indicators of population health over time. We will also compare population trends among the different sites across the state, using appropriate statistical methods that can analyse trend data collected using different survey methods (e.g. scat and spotlighting surveys).

Location

Local-scale population dynamics data should be collected from sites spread across the range of the koala in NSW. The criteria for site inclusion in the Framework are given in section 8.

Timeframe and repeat survey

Local surveys should be conducted between September and December. This period has been chosen to coincide with peak koala activity during the breeding season. Consistent

timing of surveys among sites and among years is important so that seasonal variation due to more extensive movements during the breeding season and dispersal of juveniles is not confounded with longer-term temporal changes. We recommend that our partners who survey koalas using visual surveys consider timing their surveys in September, so they can detect back young before weaning and thus gain a relative measure of reproductive success (see section 6.2.3).

Local surveys should be repeated every 1–5 years, as detailed in Table 2. Changes in trends (for example, significant decreases in relative abundance at an LGA scale) may indicate the need for more frequent local surveys, requiring an adaptive monitoring approach.

Some sites may have historical data or ongoing monitoring. These data may have been collected at different periodicities and in different seasons to those described in the Framework. Further, surveys that use newer technology such as thermal imaging from drones need to be done in the cooler months of the year (see Box 3 for details).

Methods

Under the Framework, well-established methods are used to survey population trends in koalas. The most appropriate method for each site would be used, as chosen by local research groups, based on environmental aspects such as vegetation density, tree size, topography, accessibility and the size of the site. We would work with monitoring groups to ensure that their methods are effective and validated, as outlined in the site criteria (section 8).

For a method to be suitable for monitoring, ideally it would: (i) be fit-for-purpose; (ii) have previously been used in a monitoring or survey context; (iii) include an estimate of detectability; (iv) have been researched to gain an understanding of its advantages and limitations; and (v) have been subject to peer review through publication in a scientific journal. Where new sites are established, we would consider and recommend methods that are best suited to individual sites.

The following four methods are considered well established and validated through peer-reviewed research publications:

1. **Scat surveys:** Koala scat has been used extensively for surveys (Rhodes et al. 2006; Phillips and Hopkins 2008; Phillips and Callaghan 2011; Lunney et al. 2014; Phillips 2016; Phillips et al. 2021), including monitoring over time (Department of Environment, Climate Change and Water NSW 2010; Lunney et al. 2016a, 2017; Office of Environment and Heritage NSW 2016). Methods based on the Regularised Grid-Based Spot Assessment Technique are effective for monitoring koala occupancy (Phillips and Callaghan 2011) and the limitations associated with scat detectability are well-documented (Rhodes et al. 2011; Cristescu et al. 2012; Woosnam-Merchez et al. 2012; Jiang et al. 2019).
2. **Visual surveys (diurnal and nocturnal):** replicated diurnal and spotlighting transects have been used to determine the relative density of koalas. Spotlighting was found to be 3.25 times more effective at detecting koalas than day searches (Wilmott et al. 2019); however, topography, accessibility and canopy density may preclude spotlighting at some sites.
3. **Passive acoustic monitoring:** Song meters have been used to monitor koalas over time, using estimates of detectability and the likelihood of occupancy (Law et al. 2017a, 2017b, 2018). Current algorithms are only effective at detecting male koalas. Passive acoustics are less effective outside the breeding season when bellows are less frequent (Ellis et al. 2011; Law et al. 2017a). Passive acoustic monitoring is suited to regional/landscape rather than local-scale monitoring, but research is in progress to

assess the capabilities of using local arrays of song meters for determining male koala density at site scales (B. Law, pers. comm.).

4. **Scat detection dog surveys:** Dogs are able to search a range of habitats successfully (Leigh and Dominick 2015) and have a much higher scat detection rate than humans, are more efficient and accurate, and reduce survey time (Cristescu et al. 2015). However, it is costly to train a detection dog and documentation of training methods to allow comparisons among dogs (Leigh and Dominick 2015) as well as aversion therapy to snakes and 1080 bait are required.

Koala density

Although the focus of the Framework is on trends in koala populations, the density of koalas at a site (e.g. the number of koalas counted per hectare) should also be assessed to calibrate and validate trend data derived from occupancy-based methods. This is because trends derived from occupancy surveys are not directly comparable to those from surveys that estimate numbers of animals (Bayraktarov et al. 2020). Surveys of koalas should be stratified appropriately (e.g. by plant community type or land-use category) to allow modelling across the wider region. They should be done approximately every 5–10 years, depending on the trends observed at the site.

When monitoring the effectiveness of conservation actions, a minimum of two density estimates would be required to determine the change in koala numbers at a site: one at the beginning and one at the end of the reporting period. Preferably, sites with conservation actions should be compared to a range of control areas where actions are not occurring; however, it could be difficult to find control sites that are comparable.

It is recognised that estimating koala density is challenging and resource intensive. We should invest in new technologies that will make estimates of koala numbers more feasible and cost-effective, such as thermal imagery from drones and acoustic monitoring arrays (Box 3; Law et al. 2021).

Box 3: Remotely piloted aircraft systems

Remotely piloted aircraft systems (RPASs), or drones, are emerging as a promising new method for detecting and surveying koalas. Research into the utility of thermal imaging from drones for surveying different species including the koala, is underway (Gonzalez et al. 2016; Meynink and Bourne 2017; Hodgson et al. 2018; Corcoran et al. 2019; Beranek et al. 2020; Hamilton et al. 2020; Witt et al. 2020). Affordable drones with thermal sensors are rapidly becoming more sophisticated, cheaper and more versatile. Thermal imaging currently relies on a temperature differential between the koala and ambient temperatures, which means it works best at cooler times of the day and in cooler seasons.

Paralleling the development of drone technologies, the application of artificial intelligence to object detection and classification is becoming more accessible. Shared object detection algorithms are important as a labour-saving device but also act to ensure consistency and repeatability of detection.

Further research is required on survey design for long-term monitoring, the effects of environmental conditions such as canopy density on detectability and navigation of landscape features (e.g. gullies and ridges).

New methods

The adaptive monitoring approach to the Framework enables survey methods to be changed if effective new methods and technology become available over time, and have undergone validation of accuracy, detectability and demonstration of effectiveness for use in the context of a long-term monitoring program.

Analysis

Analysis of results varies according to the survey method. For example, scat surveys (regularised grid-based spot assessment technique) and song meters are used to determine koala occupancy, whereas spotlighting surveys give a measure of relative koala density. Surveys need to be designed, and analyses planned, in consultation with a statistician to ensure that they have sufficient power and precision to detect change over time at a site. Nevertheless, change over time, particularly a decrease in koala numbers, may affect the survey design and analysis and necessitate ongoing adaptive monitoring.

3.3.3 Modelling numbers and trends based on an expert elicitation process

Modelling approaches, based on koala numbers and population trends gained from expert elicitation processes such as Adams–Hosking et al. (2016), may also be used. This may be particularly appropriate to inform management in situations such as the extensive 2019–20 bushfires in NSW when access to firegrounds was not possible immediately after the fires. This approach complements on-ground surveys.

3.4 Data evaluation

Trends in koala populations should be evaluated every year to ensure that if population changes reach the sampling objectives and decision triggers, the process of data evaluation detailed in section 10.4.1 is followed and a recommendation for action made. It is important to do preliminary analysis of data every year to ensure that no sudden changes have taken place and to gain an idea of any consistent upward or downward trends over time.

4. Koala habitat

Koala populations need large areas of connected habitat to maintain their viability. Habitat loss and fragmentation has resulted in population decline and has been identified as a significant threat to the species' persistence in NSW.
NSW Chief Scientist and Engineer 2016

Habitat loss is a key threat for koalas (McAlpine et al. 2006a, 2015; Lunney et al. 2016b; Hemming et al. 2018). Koala population sizes increase with the area of forest habitat and habitat patch size, and decrease with distance between forest patches (McAlpine et al. 2006b). Under the Koala Monitoring Framework (the Framework), the proportion of potential and known koala habitat that is lost as well as the amount of habitat that has been protected (through additions to the national park estate or through the Biodiversity Conservation Trust) and created by bush regeneration or revegetation actions should be assessed every year.

Given the difficulty of monitoring animal populations, it is often suggested that we should only monitor their habitat. Although monitoring habitat is essential, it may provide limited information as we often have a poor understanding of wildlife/habitat relationships. We may not choose the best habitat indicators, consider disturbance history, factor in human disturbance or consider intrinsic factors such as disease (Holthausen et al. 2005). With respect to koalas, we are still piecing together the many factors that contribute to tree choice (Moore and Foley 2000, 2005; Office of Environment and Heritage 2018). Disturbance history, land development and disease are certainly important factors in population change, but we have limited understanding of how they interact and what their impact is across space and time. In this monitoring framework, habitat, a major factor implicated in koala persistence (McAlpine et al. 2006a; Lunney et al. 2016b), and koala populations are monitored to improve our understanding of population change over time.

4.1 Objective

The objective is to determine the extent and location of change (loss or creation) or disturbance (due to fire) of potential and known koala habitat over time.

4.2 Location

Changes in koala habitat should be assessed from maps that cover the full extent of NSW. For assessment of regional trends, the state has been divided into nine koala modelling regions, created to match existing koala management areas as closely as possible and avoid splitting up areas of regional koala significance (ARKS). The regions are: North Coast, Central Coast, South Coast, Central and Southern Tablelands, Northern Tablelands, Northwest Slopes, Darling Riverine Plains, Riverina, and Far West (Figure 2).

4.3 Timeframe and repeat survey

The first assessment should be conducted in 2021 and then be repeated every year. Assessments of historic koala habitat may also be made for comparison.

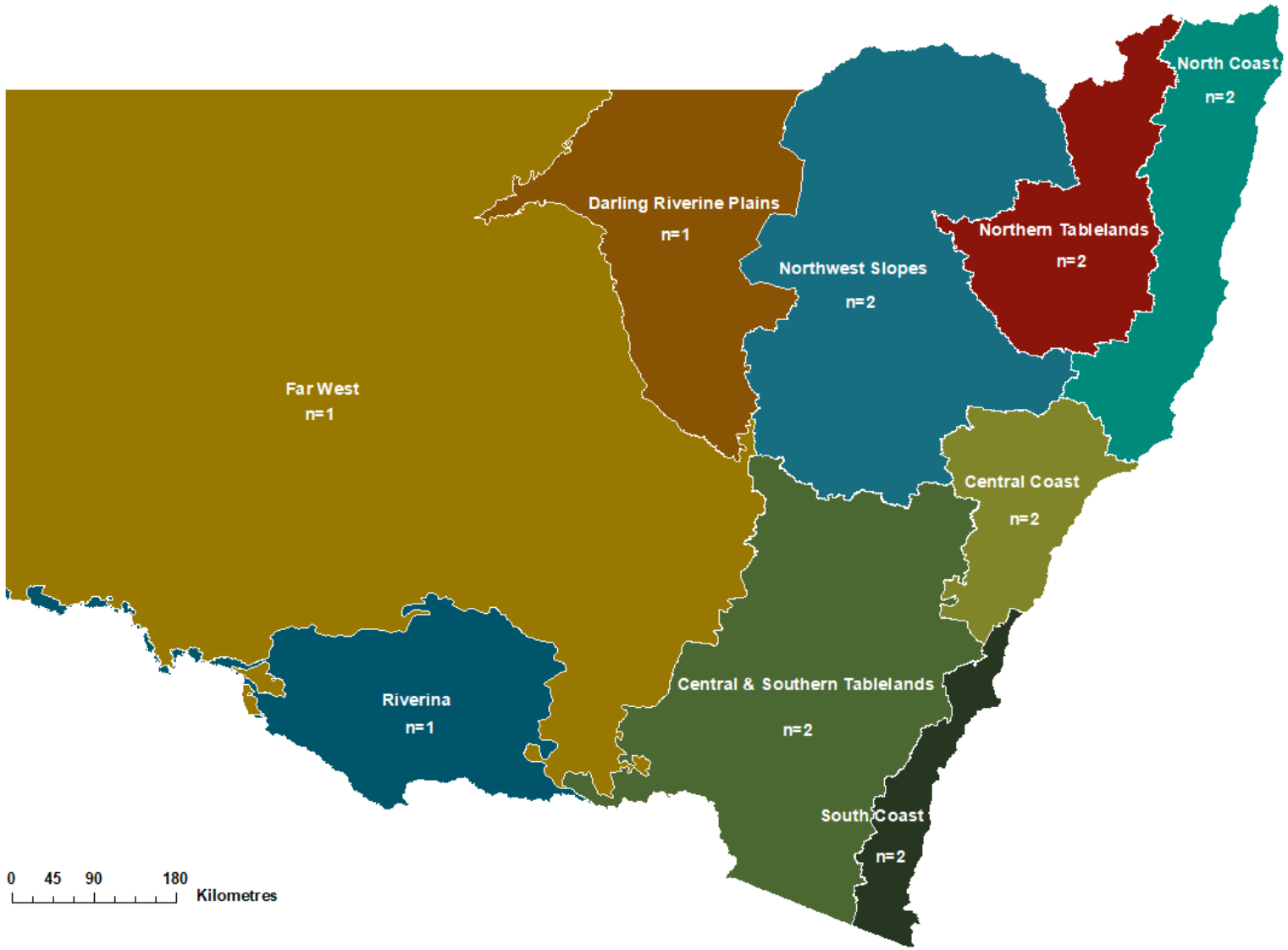

Figure 2 **Proposed spread of local monitoring sites across koala modelling regions in NSW; n = minimum number of long-term monitoring sites (see section 8.1)**

4.4 Methods and analysis

To monitor the loss of koala habitat, the annual assessment of vegetation change or Statewide Landcover and Tree Study (SLATS), should be overlaid on the Koala Habitat Suitability Model (KHSM) and other spatial layers, including:

- KHSM: to assess lost potential koala habitat across five suitability classes (very high, high, moderate, low, very low) which are intended to represent a gradual decline or increase in habitat quality
- Koala Likelihood Map (KLM): to quantify loss of habitat where koalas are known to occur
- ARKS: to indicate losses occurring in areas of regional koala significance
- core koala habitat mapped in comprehensive koala plans of management: to indicate loss of koala habitat at the local government area (LGA)
- Koala refugia: to assess loss of potential koala refugia.

Disturbance to koala habitat due to fire should be assessed by overlaying fire extent and severity maps on the KHSM. The overlapping areas equate to the affected potential and known koala habitat.

We should also determine gains in protection or creation of koala habitat by assessing the amount of revegetated land, recent land acquisitions (for example, the purchase of Tugalong Station in the Southern Highlands) and new private land conservation agreements offered by the Biodiversity Conservation Trust (following koala tender programs in the Kempsey–Port Macquarie and Lismore–Ballina areas).

4.4.1 Details of layer generation

Statewide Landcover and Tree Study

Woody vegetation change data is derived annually from analysis of satellite images by the NSW Department of Planning, Industry and Environment (the Department) Remote Sensing and Regulatory Mapping team, using the SLATS methodology. This is required under the *Local Land Services Act 2013*. The SLATS data are obtained from Sentinel satellite imagery with 10-metre pixel size. Woody vegetation clearing is detected using a combination of automated change algorithm and expert interpretation. Once confirmed, clearing is coded according to landcover type (e.g. agriculture, infrastructure or forestry). This data is in raster format. The first dataset relevant to the Framework is SLATS 2017, which uses pre-clearing imagery captured as close as possible to 1 January 2017 and post-clearing imagery near 1 January 2018. Currently, SLATS data has been processed up to 2019 and 2019 summary statistics are available online (NSW Department of Planning, Industry and Environment 2021).

Koala Habitat Suitability Model and Koala Likelihood Map

The Koala Habitat Information Base includes the KHSM and KLM layers, which have been developed by Science, Economics and Insights Division teams in the Department (NSW Department of Planning, Industry and Environment 2019a, 2019b).

- The KHSM provides a data-driven prediction of the distribution of potential koala habitat based on a MaxEnt (maximum entropy modelling) model. The model uses koala site data, environmental predictors and an index of vegetation suitability to predict potential habitat. The model defines the dimensions of the ecological niche typical of known koala locations and predicts the occurrence of this niche across the landscape. The layer is generated for a given region and may require a local assessment to confirm actual

occupancy. The surface is derived with a set of environmental rasters at a 30-metre pixel resolution.

- Unlike the KHSM, the KLM is driven directly by the available data on koala occurrence without the use of environmental or vegetation data and, therefore, is not a potential habitat map but rather a relative likelihood of occurrence map. It is built using available arboreal mammal records from the past 20 years and is the simple proportion of arboreal mammal records within an area (10 square kilometre grid cell) that are koalas (Predavec et al. 2015). The records of other arboreal mammals provide a measure of survey effort independent of koalas. The map also includes a relative measure of the confidence in the koala likelihood estimate. This enables deficiencies in the data to be highlighted, and recommendations to be made for areas requiring further survey.

Areas of regional koala significance

ARKS use information on koala occurrence to identify key koala populations and management areas with potential for long-term viability. They also identify priority threats to key koala populations at the regional scale (NSW Department of Planning, Industry and Environment 2019b). ARKS have been mapped across NSW using an analysis of koala observation densities, which incorporates estimates of koala home ranges and their ability to move across the landscape, and excludes areas of non-habitat (Office of Environment and Heritage NSW 2019).

Potential koala refugia

This layer is a simple recalculation of fire extent and severity mapping (FESM) classes representing potential 'refugia' of unburnt and low severity pixels within fire extents for the 2019–20 fire season (R. Gibson, unpublished data).

Core koala habitat layers

These were mapped for LGAs as part of comprehensive koala plans of management made under koala habitat protection state environmental planning policies and are available from local councils.

Fire extent and severity mapping

FESM is a semi-automated approach to mapping fire extent and severity through a machine learning framework based on Sentinel-2 satellite imagery (10-metre pixel size), developed by the Department's Remote Sensing and Regulatory Mapping team in collaboration with the NSW Rural Fire Service. The statewide severity mapping has standardised classes to allow comparison of different fires across the landscape. The FESM severity classes include: unburnt, low severity (burnt understory, unburnt canopy), moderate severity (partial canopy scorch), high severity (complete canopy scorch, +/– partial canopy consumption), extreme (complete canopy consumption) (State Government of NSW and Department of Planning, Industry and Environment 2020).

4.4.2 Sampling objective

To determine trends in the amount of potential koala habitat (losses and gains) at the statewide and regional scales (at a resolution of 10 metres – i.e. the spatial resolution of the SLATS data).

4.5 Data evaluation

The extent of potential and known lost koala habitat should be assessed every year.

5. Genetic diversity

Preventing the decline of genetic diversity in NSW is a key factor in protecting the resilience of our koala populations… A program of gathering genetic data would therefore strengthen understanding of the health and dynamics of NSW koala populations.
NSW Chief Scientist and Engineer 2016

The success of conservation actions is often measured in terms of numbers of animals. However, numbers by themselves are not meaningful if these animals are inbred (Schultz et al. 2020) or have experienced substantial loss or disruption to genetic diversity at both the individual and population level. Genetic analysis provides critical insights for large-scale population management, such as population structure, indicating which populations experience higher or lower levels of gene flow. It also gives insight into the physical pathways of connectivity that are crucial to maintain for population longevity.

Genetic analysis provides important information at the population level, which is not obvious through observation or simple numerical monitoring, such as how genetically diverse each population is. This includes how genetically related animals are between sample sites, which may indicate barriers to movement and recent or historic impacts on a population, such as bottlenecking. For example, reasonably rapid genetic differentiation can be caused by habitat fragmentation due to infrastructure and residential development (Lee et al. 2010), and certain koala populations in NSW have comparatively high levels of genetic diversity that must be maintained for long-term population health (Dennison et al. 2016; Neaves et al. 2016; Johnson et al. 2018).

Snapshot 3: The koala genome

A team of 54 scientists, led by the Australian Museum Research Institute Director, Professor Rebecca Johnson and Professor Katherine Belov at the University of Sydney, recently sequenced the koala genome, producing a complete and contiguous marsupial reference genome (Johnson et al. 2018). It revealed information about the koala's ability to detoxify eucalypt leaves, its immune response to chlamydia and lactation proteins that protect pouch young.

What did it tell us about koala populations?

The genome showed geographic clustering of wild koalas related to proposed biogeographic barriers at the Brisbane and Clarence River Valleys and in the Hunter Valley. This indicated three genetically different populations in NSW that, while identifiable as distinct populations, do experience inter-population geneflow. These populations form the basis of the genetic monitoring in this Framework.

Assessing functional genetics and genomics over space and time will inform future translocation and genetic rescue by determining populations that show evidence of local adaptation (Sodhi and Ehrlich 2010). Effective translocation and/or captive breeding of individuals that show adaptation to local conditions can build genetic resilience in populations, including resistance to disease and increased drought tolerance.

External scientists with genetic expertise should provide high-level advice on the direction of any genetic works (see section 10.1 for details).

5.1 Objectives

The objectives of genetic monitoring are to:

- assess population connectivity at the macro level (statewide) and where possible at the regional level (information should be a priority for conservation and monitoring action)
- assess genetic diversity of each population (previous studies indicate some populations retain a high level of genetic diversity – these should be a priority for conservation and monitoring action)
- assess how genetic diversity, including functional diversity (e.g. of immune, reproductive, behavioural and heat-tolerance genes), varies over space and time and the relationship of these data to conservation actions (e.g. translocation, genetic rescue)
- use genetic data to understand whether there has been a change to boundaries between genetically distinct populations or within a population (in response to a recent anthropogenic or natural (e.g. bushfire) change to the landscape)
- establish the level of population relatedness (i.e. existing levels of population structure and inbreeding) and monitor whether there is a change or increase in level of inbreeding.

5.2 Location

5.2.1 Sampling objectives

The sampling objectives of genetic monitoring are to:

- understand koalas at the statewide level by characterising genetic diversity at the population level (as determined by biome, habitat modelling and/or observational data)
- characterise levels of diversity and compare populations to identify the locations of high diversity which need to be conserved and of low diversity that may require genetic rescue
- detect changes and loss in genetic diversity and increases in inbreeding and/or homozygosity across the genome
- monitor and detect changes in connectivity between genetically distinct populations and increases in inbreeding between sampling periods (a koala generation – about 7 years), which would negatively affect the long-term health and survival of koala populations. Understanding and maintaining the major pathways of connectivity between locations is critical to sustainable management of koalas. For example, it gives a good idea of which populations may recolonise areas affected by catastrophic events, such as the severe bushfires that occurred in 2019–20.

Monitoring sites should be spread across the state to allow investigation of the objectives identified in section 5.1. This will include:

1. State-level sampling: Sampling across NSW (or using samples from the NSW Koala Biobank at the Australian Museum if they already exist) to ensure each of the ARKS is represented by at least 20 individuals.
2. Opportunistic sampling: A range of organisations (e.g. wildlife rehabilitation organisations, state government agencies, local councils, universities and non-government organisations) should be involved by contributing opportunistically collected genetic material. Some of these agencies already have agreements to send their genetic material to the NSW Koala Biobank at the Australian Museum. Others should be contacted to ensure the widest possible coverage across NSW.

5.3 Timeframe and repeat survey

Monitoring genetic change over time requires planning at ecologically and genetically meaningful temporal scales.

5.3.2 Collection

Genetic material should be collected continuously from wildlife rehabilitation groups and periodically from our monitoring partners (when koalas are caught for research/radiotracking) to build a large enough sample size of genetic material from koala populations across the state (Box 4). Ideally, we would also sample populations that have never been sampled before, that is within the last 1–2 koala generations (within the last 10 years).

5.3.3 Analysis

Genetic samples need to be analysed at the start of the Koala Monitoring Framework (the Framework) and then approximately once a generation, estimated as 6–8 years (Phillips 2000). However, because we do not know the average lifespan of the koalas at our sites, or whether there is a high level of turnover of koalas (e.g. due to threats), we should take a conservative approach and analyse the data every 3 years (half a koala generation), with a review at 3–6 years (R. Johnson, Australian Museum, pers. comm.).

There may be circumstances where the frequency of sampling differs. For example, if populations are found with low levels of diversity, which would benefit from genetic rescue through translocation, monitoring should be done to check that released animals are contributing to the gene pool.

5.4 Methods and analysis

Direct sampling should be used preferentially to collect genetic material. The best source of genetic material from marsupials is tissue (M. Lott, Australian Museum, pers. comm.), which can be obtained from koalas during ear-tagging when they are captured, or from koalas brought into care or wildlife hospitals. The Code of Practice for Injured, Sick and Orphaned Koalas indicates that samples must be taken from all deceased and released koalas and sent to NSW Koala Biobank at the Australian Museum (Office of Environment and Heritage NSW 2018c).

To assess population-level changes both within a population and between populations, genetic markers such as single nucleotide polymorphisms (SNPs) are becoming more popular. Tissue samples are usually taken for this method (Kjeldsen et al. 2016, 2019; Johnson et al. 2018). Different studies use different markers, and it is important that all tissue samples from surveys in the Framework are analysed using the same methods to ensure maximum interoperability of the datasets. In the future, cost and ready availability of genome sequencing would allow for whole genome sequencing of all individuals. For this reason, all tissue samples for genetic material will be stored in the NSW Koala Biobank at the Australian Museum, where they will be available for analysis for koala monitoring and for the wider scientific community to use. Samples for koala monitoring should be analysed by the Australian Museum or other research collaborators with a suitable level of scientific expertise, using appropriate marker sets (SNP or whole genome-based methods).

At locations where koala populations are very small and low density, such as the south-east coast (Bermagui–Mumbulla area) where the population is estimated at 30–60 individuals (Department of Environment, Climate Change and Water NSW 2010; Office of Environment and Heritage NSW 2016; Higgins et al. 2017), capture is not possible and carer data is minimal, so indirect sampling (scats) should be used to obtain genetic material

(Schultz et al. 2018). Analyses of genetic data amplified from scats (fresh and aged) has been used to gain information on sex, genetic diversity and infection status of south-east coast koalas (Higgins et al. 2017). It should be noted that DNA quality from scats is highly variable and affected by the age of the scat. Thus, it is not an appropriate method unless it is logistically difficult to obtain tissue samples. It should also be noted that DNA from scat samples is problematic for SNP analyses or whole-genome sequencing. At some sites, such as Pilliga and Warrumbungle national parks, where koala numbers are currently extremely low and signs of koalas (bellows, scat) are rare, it may not be possible to obtain genetic material.

Given that capturing unique alleles from small or low-density populations that are at risk of extinction is very important, new technology such as thermal imagery from drones should be explored as a technique to locate individuals for tissue sampling.

All samples for genetic analysis should be collected according to Australian Museum instructions in Appendix 1 of the Code of Practice for Injured, Sick and Orphaned Koalas (Office of Environment and Heritage NSW 2018c), which provides details for collection of tissue and scat samples. This document will be provided to all organisations collecting samples for DNA analysis.

5.5 Data evaluation

The genetic monitoring data should be evaluated after each analysis period (3–6 years, see section 5.3) to assess the data against the sampling objectives. If the changes indicated in the sampling objectives are reached, the procedure detailed in section 10.4 should be followed.

5.6 Further considerations

The data collected under the Framework may also be used to:

- investigate whether particular genes are under selection in certain populations and use this information to inform conservation actions under the Framework, including for possible future genetic rescue or translocation decisions
- develop a rapid-use genetic assay that can assign high level population location, assess genetic diversity and possibly identify adaptive genes advantageous in some populations
- inform management actions, such as conserving high-value populations or those requiring genetic augmentation.

Box 4: Participate in the statewide genome program in 2021–22

Koalas are affected by multiple threats, including climate change and disease. The NSW Government needs to better understand the adaptive potential of koala populations to these threats.

How is genomic sequencing different to sequencing SNPs?

Single nucleotide polymorphisms (SNPs) are currently the best method for comparing large numbers of individuals within and between populations. The method is targeted at the more 'neutral' parts of the genome, which mutate at a faster rate than the functional parts of the genome. This means that we obtain limited functional diversity information from this method, such as information about immune, reproductive, behavioural and heat-tolerance genes, which we need to understand the adaptive potential of populations. This sequencing is cheaper than genomic sequencing and can be used as a regular genetic monitoring method.

Genome sequencing provides baseline data on the differences within and between populations in both neutral and functional regions of the genome. This sequencing is more expensive per individual and only needs to occur every 2–3 koala generations.

How can you participate?

- Contact Wildlife.Research@environment.nsw.gov.au to find out if we need samples from your area.
- Collect two tissue samples (note that ear tissue, not ear cartilage, is needed).
- Put the tissue samples into two vials of 100% ethanol.
- Label the vials clearly and post to the address provided.
- The vials will be stored in a –20°C freezer initially with archival storage at –80°C.

What happens to tissue samples

Sample 1:

- Each time we have 94 samples, we will sequence them in a batch at no cost to you.
- SNP data will be freely available to you and the wider research community.

Sample 2:

- We will deposit the second sample in the NSW Biobank at the Australian Museum, where it will be available for genome sequencing as required.
- We will use 20 samples from each koala population for genome sequencing. If your sample is sequenced, the data will be freely available to you and the wider research community.
- If your second sample is not sequenced, you can request access to it from the NSW Biobank.

The result

You will be able to use the SNP and genome sequencing data to answer your research questions, and also contribute to the statewide genetic monitoring program.

Monitoring

Our aim is to complete intensive genomic sequencing every 10 years and SNP analysis at smaller timeframes. We may have further rounds of participation in the program in the future (i.e. after 2022).

6. Disease and reproduction

Local extinctions are possible where loss of fertility due to chlamydiosis and reduced recruitment due to habitat fragmentation cause populations to decline.
Department of Environment and Climate Change 2008

Monitoring of indicators of population health, such as disease, often gives better estimates of trends than numbers of animals (Holthausen et al. 2005). Thus, it is important to include this in the planning phase of field-based surveys (Koala Heath Hub, unpublished report). The Koala Monitoring Framework (the Framework) recommends monitoring infection by *Chlamydia pecorum* (*C. pecorum*) and reproductive success as an indicator of trends in koala health across NSW.

External scientific experts with disease expertise (auxiliary members of the Koala Monitoring Expert Panel) should provide high-level advice on the direction of any work on disease in koalas (see section 10.1).

6.1 Objective

The objective of monitoring indicators of population health is to assess how disease and reproduction vary spatially and temporally.

6.2 Survey design overview

Under the Framework, trends in health and reproduction should be monitored using:

- a citizen science approach, such as a statewide community wildlife survey
- targeted studies of disease and reproduction at local sites across the state
- collaborations with agencies studying koala disease or radiotracking koalas as part of other research projects.

Table 3 gives a summary of the design. The community survey gives us an understanding of community perceptions of koala disease trends. Data collected from koala populations at the local scale provide targeted, site-specific information that can be used to determine management and conservation actions.

6.2.1 Location and spatial scale

The criteria for local site inclusion in the Framework are given in section 8. We recommend monitoring:

- Disease prevalence at a subset of local sites spread across the State. A robust survey design for detecting change in the proportion of *C. pecorum*-positive individuals in a population over time requires large sample sizes and is resource-intensive. Thus, fewer sites with greater allocation of resources and targeted epidemiological expertise will give the best results.
- Reproduction at all sites where wildlife rehabilitation data is available and at a subset of sites where koala spotlighting or capture is undertaken as part of other concurrent monitoring or research programs.

- Community sightings of trends in disease and reproduction at all scales (statewide, regional and local) where there is sufficient community participation to robustly analyse data.

Table 3: Design for koala disease and reproduction monitoring

What is to be monitored?	What are the sampling objectives? A decision trigger is activated if there is:	What data do we want?	Example methods	Initial frequency
Disease Prevalence of *Chlamydia pecorum* (*C. pecorum*)	A 30–40 percentage point difference in the proportion of koalas testing positive for *C. pecorum* at a site between sampling intervals Introduction of disease to a site which is currently considered *C. pecorum*-free	Proportion of scat surveyed	Scat surveys (collection)	Every 1–5 years
		Proportion of koalas seen during surveys	Visual surveys	Concurrently with population trend surveys (section 3.3.2)
		Proportion of koalas captured for research	Koala surveys (capture for swab samples, physical examination)	Frequency based on research programs
Community sightings of koalas showing manifestation of disease (clinical signs)	A significant change in the community's sightings of disease between surveys	Proportion of sick koalas	Community survey (section 3.3.1)	Every 5 years
Reproduction Reproductive success	A change in the proportion of female koalas with young at a site between sampling intervals	Proportion of female koalas with young	Rehabilitation records	Every year
			Visual surveys	Concurrently with population trend surveys (section 3.3.2)
			Koala surveys (capture)	Frequency based on research programs
			Community wildlife survey (section 3.3.1)	Every 5 years

Notes: Percentage point represents the minimum difference that we will be able to detect given the sample sizes that are likely to be achieved: 25-49 koala/scat samples/site with 95% confidence and 80% power, calculated across a prevalence range of 10–80% of a population (Sergeant 2019).

6.2.2 Disease

'…the most striking finding was the relative lack of population-level disease studies within the last two decades to examine mechanisms of chlamydial infection dynamics.'

(Grogan et al. 2017)

There have been few longitudinal disease monitoring studies of koala populations, perhaps partly because they require a multi-disciplinary approach, involving ecologists, veterinarians

and epidemiologists. Currently, there are no published, long-term disease monitoring programs in NSW. However, there is an ongoing, in-depth study of koala populations in Gunnedah (M. Crowther, pers. comm.).

Research indicates chlamydiosis has an effect on fertility and breeding frequency (McLean and Handasyde 2006; Lunney et al. 2012; Fabijan et al. 2019), and use of koala rehabilitation data has allowed landscape-level analysis of disease prevalence related to changes in land-use and climate (McAlpine et al. 2017). However, evidence of the role of chlamydiosis as a cause of koala declines at the population scale is not robust, likely due to non-representational sampling of some studies (Grogan et al. 2018). In the Framework, we focus on long-term monitoring of *C. pecorum* prevalence.

Snapshot 4: *Chlamydia pecorum* and reproduction in Gunnedah

In the early 2000s, the koala population of the Liverpool Plains near Gunnedah was increasing. Following a long drought, it was estimated that about one quarter of this koala population died during heatwaves in November and December 2009. It was also discovered that chlamydiosis had emerged in the region in 2008, although the area was anecdotally considered chlamydia-free. Initial results from surveys in 2010–11 indicated that clinical disease was evident in males and females, and that there was increased prevalence of *C. pecorum*. The percentage of young koalas detected during koala catching for radiotracking also dropped between 2008–09 and 2010, which was interpreted as a delayed drop in condition following the drought and heatwaves (Lunney et al. 2012).

What are the trends in Gunnedah now?

Koala numbers continue to decline. Since 2009, there has been a 10–30% population reduction at study sites (Crowther et al. 2019). It is considered essential to increase reproductive success in this population.

Current conservation actions include supplementing water (Mella et al. 2019) and vaccinating against chlamydiosis (NSW Department of Planning, Industry and Environment 2019c). The only way we can determine whether these actions have been successful is to continue to monitor reproductive success, disease prevalence and relative abundance of koalas over several generations in Gunnedah.

Survey design details

Collaboration with experienced researchers is considered essential to ensure novel epidemiological and statistical approaches are applied to detailed project design and analysis. Monitoring should be done at the local spatial scales relevant to each site, based on:

- monitoring history (populations of koalas with a history of disease monitoring in NSW)
- landscape features and private tenure restrictions (populations can be widespread in cleared farmland areas or restricted to corridors of bushland within fragmented urban contexts)
- wildlife rehabilitation data availability and utility (local to regional areas, e.g. Friends of the Koala, Port Macquarie Koala Hospital and Koala Health Hub)
- sample size requirements for analysis of temporal trends (to sample sufficient numbers of koalas for analysis, larger areas may be required for low-density populations than higher density populations)

- management relevance (local government area (LGA) or multi-LGA scales are most appropriate).

Our monitoring partners should collect this data using one of the following methods:

- **Direct sampling** – sampling koalas directly is the most reliable way of obtaining information on koala health and disease. Koalas caught for disease research and/or as part of radiotracking projects involves:
    - Veterinarians evaluating koala health and condition in the field and taking samples to test for disease, which allows quantification of the relationship between infection and expression of the disease. Koalas in a population may be infected with *C. pecorum*, but have no clinical signs, or they may exhibit symptoms such as wet bottom, which indicates the disease is having an impact on health and reproduction.
    - Catching koalas, which is resource intensive, difficult for many low-density populations and may result in relatively small sample sizes or make this approach unfeasible at some sites.
- **Scat sampling** – scat sampling is a non-invasive method of determining disease prevalence (Wedrowicz et al. 2016, 2018; Schultz et al. 2018; Cristescu et al. 2019). Scat should be collected:
    - during Regularised Grid-Based Spot Assessment Technique surveys for occupancy
    - during spotlighting when koalas are found as this allows the collection of fresh scat from individuals as well as an assessment of clinical signs of disease in the field
    - in scat surveys dedicated to disease detection, for example, in areas where *C. pecorum* has not been found, a risk-based approach has been used by sampling at the most likely incursion pathway (D. Higgins, pers. comm.).

The sample size required to detect change in *C. pecorum* prevalence over time is calculated using an online tool (Sergeant 2019). This tool calculates the number of samples required to detect a statistically significant difference between two proportions with specified levels of confidence and power. Where scat is used for disease analysis, it is necessary to accurately quantify the sample size, either by identifying individual koalas using DNA from the scat or reducing the likelihood that the same koala is sampled twice. This can be achieved by sampling fresh scats at a site over a period that is too short for most koalas to move (i.e. on the same night) and/or separating sites by a distance of 500 metres to 1 kilometre. Disease samples will be collected according to the sampling protocols developed by the Koala Health Hub (Koala Health Hub 2019).

In addition, data from observations of clinical signs of disease (e.g. wet bottom or conjunctivitis) during spotlighting, and community sightings of koalas with disease collected during the community wildlife survey can be used to monitor change in clinical signs of disease over time (Table 3).

Analysis

Analysis of scat and tissue samples for *C. pecorum* needs to be done by organisations experienced in this field. Examples include the Koala Health Hub (Fernandez et al. 2019) OWAD Environment and WildDNA/Federation University (Wedrowicz et al. 2016). The same methods need to be used consistently at a site to ensure comparability between sampling periods because the sensitivities and relative performance of the various methods have not been adequately cross validated (D. Higgins, Koala Health Hub, pers. comm.).

6.2.3 Reproduction

Koala rehabilitation records can be used to monitor the proportion of koalas coming into care with young over time. As part of the NSW Koala Strategy, the NSW Government is working

closely with fauna rehabilitation groups and wildlife hospitals to make sure information is captured to help us better understand the number of koalas being cared for, the reasons that koalas have come into care (e.g. *C. pecorum*, dog attack), their length of stay, and the treatment received (Office of Environment and Heritage NSW 2018a, 2018c). The Code of Practice for Injured, Sick and Orphaned Koalas details standards and guidelines for record keeping. Koala rehabilitation records include several categories of young (pinkies, furred pouch young, back young and independent young still with their mother).

Reproductive success can also be determined from observations during visual surveys (spotlighting and diurnal; see section 3.3.2) and direct sampling of koalas at sites where they are caught for radiotracking or disease studies. Koalas can be checked for pouch young on capture, and the capture tree can be searched for independent young still with their mother. Data from community wildlife surveys can also be used to monitor the community's sightings of the number of koalas with young over time (Table 3).

6.3 Data evaluation

The data should be evaluated after each analysis period (every 1–5 years; see Table 3) to assess the data against the sampling objectives.

6.4 Further considerations

Another well-known disease, koala retrovirus (KoRV), will not be monitored in the Framework because all samples are likely to be KoRV A positive and KoRV B is difficult to analyse. Furthermore, the significance of KoRV B is unknown, and as swabs and scats have not been validated for KoRV B, it is not of immediate value.

The Koala Health Hub will archive any extracted DNA so it could be assayed later, as funding and better methods become available (D. Higgins, pers. comm.). As a priority, research into the immune consequences of KoRV on koala populations should begin to ensure that we understand the role of KoRV in koala health.

7. Threats

The koala presents the problem of managing a wide-ranging species that now primarily occurs in human-modified landscapes, some of which are rapidly urbanising… The implementation of policy to conserve remaining koala habitat and restore degraded habitat is critical to the success of koala conservation strategies, but habitat conservation alone will not resolve the issues of koala conservation. There needs to be concerted effort to reduce the incidence of dog attack and road-related mortality, disease prevalence and severity…
McAlpine et al. 2015

The threats to koalas are well documented (Department of Environment and Climate Change NSW 2008; McAlpine et al. 2015). Their impacts on populations vary across the distribution of the koala as well as at local scales (Lunney et al. 2016b). In the northern half of the koala's range in NSW and Queensland, where population declines are common, habitat loss, hotter droughts, disease, dog attacks and vehicle collisions are the major threats whereas southern populations in Victoria are locally overabundant and are now subject to managed declines (McAlpine et al. 2015).

Assessment and monitoring of some of these threats is addressed in other sections of the Koala Monitoring Framework: koala habitat loss (including habitat change due to bushfire) in section 4; disease monitoring in section 6; and the effectiveness of projects/actions targeting threats in section 9. In addition, wildlife hospital and rehabilitation records (Griffith et al. 2013; Mo et al. 2020; Charalambous and Narayan 2020) and data from the community wildlife surveys can be used to monitor threats to koalas when they are in contact with urban and peri-urban environments.

This section focuses on a spatial analysis of multiple threats at local and regional scales across NSW and how the relative intensity of these threats changes over time. This analysis may reveal correlations between a proximate or immediate threat (e.g. predation by wild dogs, increased vehicle strike) and the ultimate or wider threat (bushfire, fragmentation of habitat). This information could be used to set location-specific targets aimed at lowering threats.

Snapshot 5: Threat data from rehabilitation records

To identify the threats to koalas on the mid-north coast of NSW, Griffith et al. (2013) compared admission records from a rehabilitation centre over a 30-year period to assumed wild population demographics.

What did they find?

Trauma (motor vehicle accident and dog attack) and clinical signs of chlamydia were the most frequent admission groups. Trauma most often affected young and male koalas, whereas koalas presenting with signs of chlamydia were aged. This study highlighted the potential of koala rehabilitation records to detail threats to local koala populations and provide an evidence base for local threat mitigation.

7.1 Objective

The objective of threat monitoring is to assess how the relative intensity of threats varies spatially and temporally.

7.2 Location

Threats should be assessed at each of the sites at the local scale (data permitting) and across larger regional scales.

7.3 Timeframe and repeat survey

Assessment of threats at the local scale needs to take place every year. Data from the community wildlife surveys should be available every 5 years (see section 3.3.1 for full details).

7.4 Methods and analysis

Threats encountered by koalas in urban and peri-urban contexts can be monitored using koala rehabilitation records (Gonzalez–Astudillo et al. 2017). This dataset is best suited to monitoring the relative impacts of vehicle strike, disease (e.g. chlamydia), and dog attack on koalas in areas near human development. These records include information on cause of entry, success of care and, in some cases, post-release monitoring. The data are more likely to give information on injured or ill koalas than deaths, which are not always recorded and are thus underestimated.

Currently, research is being done in the Science, Economics and Insights Division of NSW Department of Planning, Industry and Environment to realise the full potential and utility of these data. The data varies among carer groups and years but is useful for determining changes in the relative proportion of threats at the local scale. The data can also be useful as a starting point for researching a range of wider threats to koalas (D. Lunney, pers. comm.). For example, if increased numbers of koalas are presenting with chlamydia, date and location information can be used to determine whether there is a correlation with a severe drought or other factors that may be causing stress and impacting the population (McAlpine et al. 2017).

Data from the community wildlife survey can be used to assess the spatial arrangement of ranked threats. Comparison of future surveys would enable detection of changes in community perceptions of these ranked threats.

7.4.1 Sampling objectives

The sampling objectives of threat monitoring are to detect a significant change in:

- the relative proportion of threats at a site between sampling intervals
- the community's perceptions of ranked threats spatially and between 5-yearly surveys.

7.5 Data evaluation

The threat assessment should be evaluated every year to assess the data against the sampling objectives.

8. Site inclusion

Local- to regional-scale monitoring of population dynamics, health and reproduction, and threats can be achieved through collaborations with a range of agencies and partners at sites across NSW. Site inclusion in the Koala Monitoring Framework (the Framework) will be based on specific criteria, adapted from Woinarski (2018), to ensure a robust sampling design and effective local scale monitoring.

8.1 Criteria

Where possible, sites included in the Framework will include:

- **Coverage**
  - be spread across the range of the koala in NSW
  - be spread across the Koala Modelling Regions where long-term monitoring is feasible due to sufficient numbers of koalas (Figure 2)
  - be included in priority areas of regional koala significance (ARKS)
  - be situated in areas where koalas are known from sighting data or have a high likelihood of being found (based on the Koala Likelihood Map), and where habitat has been categorised as suitable (based on the Koala Habitat Suitability Model and local government area (LGA) maps associated with comprehensive koala plans of management
  - be spread across different land tenures, areas that were burnt and unburnt during the 2019–20 bushfire season and, where possible, across areas that include different threats to koalas
  - be geographically separated by at least 8 kilometres so they are independent and avoid spatial autocorrelation (McAlpine et al. 2006b)
- **Fit-for-purpose and design quality**
  - have a current monitoring program using well-established methods that have been demonstrated to optimise detectability and effectively estimate trends in populations and which are suited to the spatial scale of the areas to be sampled (e.g. local site or landscape/LGA scale)

  or

  - demonstrate their ability and capacity to establish a monitoring program as an addition to their current koala research or conservation actions (all sites)
  - include a measure of disease prevalence and reproductive success, collected without bias or with documented biases allowing appropriate correction techniques (a subset of sites)
  - have a design demonstrating sufficient statistical power to detect change over time, developed in consultation with a statistician or ecologist
- **Sampling periodicity and longevity**
  - conduct monitoring at the timeframes required by the Framework
  - commit, in principle, to 10+ years of monitoring, pending funding
  - have historical monitoring data (preferable)
- Data reporting
  - make available relevant historical and current monitoring data
  - upload data to BioNet every year
- **In-kind contributions, community support and agency collaboration**

- leverage in-kind contributions, have local community engagement and support, and collaborate with other organisations in the local area (e.g. councils, not-for-profits)

- **Dependencies/risks**
  - not rely solely on financial sources or resources that are unreliable and could put the Framework at risk.

9. Project/action-based monitoring

A range of local management actions that target threats to koalas are being implemented throughout NSW by government, community and not-for-profit agencies, including projects with support from the NSW Koala Strategy (the Strategy) and Roads and Maritime Services (Office of Environment and Heritage NSW 2017, 2018a; NSW Department of Planning, Industry and Environment 2019d; Roads and Maritime Services 2019). Monitoring these projects is important so that we can assess their success and use this evidence to inform management of koalas. Gaining an understanding of the effectiveness of these actions may also inform our understanding of local-scale koala population trends. For example, if conservation actions improve the health of local koala populations, we may detect an increase in density and reproduction, and a decrease in disease prevalence through monitoring over a number of generations.

9.1 Objectives

The objectives of monitoring the outcomes of koala conservation projects and actions are:

- to evaluate the effectiveness of conservation projects and the return on investment (time and resources)
- to provide evidence to inform the community and government about how conservation projects have affected koala populations
- to facilitate adaptive learning, which can be applied to koala management.

These objectives have been adapted from the monitoring objectives of the *Saving our Species* program (Office of Environment and Heritage NSW 2018d). Overall, these objectives allow adaptive management and changes to actions in the Strategy if the aim of stabilising koala populations is not being achieved.

9.2 Management and conservation actions

Local management actions have project-specific goals, timeframes, locations and monitoring designs. These actions include:

- koala rehabilitation by carer groups and in wildlife hospitals
- planting trees to restore and connect koala habitat
- weed eradication in koala habitat
- local actions to reduce vehicle strike and dog attacks
- artificial water sources for koalas in heatwave and drought prone areas
- piloting koala conservation reserves across private and public lands
- koala relocation and translocation
- cultural burning
- fire planning, including interpretation of the impact of fires on koala populations and monitoring recovery so we can plan for future fires and manage priority populations.

9.3 Monitoring, evaluation and reporting

The design and methods for these conservation actions are not prescriptive but vary according to the management action, the site, and resources available.

Guidance can be given when required on identifying:

- the correct questions
- SMART (specific, measurable, achievable, relevant and time-bound) sampling objectives
- a robust study design with sufficient statistical power
- the appropriate values to measure
- monitoring methods
- data analysis
- data storage
- reporting to the Department of Planning, Industry and Environment.

Monitoring of these actions should be guided by the comprehensive document, *Saving our Species* Monitoring, Evaluation and Reporting: Guidelines for conservation projects (the MER Guidelines; Office of Environment and Heritage NSW 2018d). The primary focus of monitoring, evaluating and reporting (MER) is to evaluate the response of the koala to management at the sites of investment. The MER Guidelines ensure that monitoring the outcomes of actions will be rigorous and effective, evaluation of outcomes will be consistent, and reporting will be clear and meaningful to all stakeholders.

The MER Guidelines detail:

- The principles of site-based monitoring, when to use adaptive management, the appropriate scale of monitoring and best-practice governance of the project. An adaptive management approach is recommended when there is high uncertainty in the system under management. For example, there may be uncertainty about the relative effectiveness of different threat-abatement techniques (e.g. fences, signs, culverts for vehicle strike reduction) or different treatment methods for disease at koala hospitals. If this uncertainty is inhibiting effective management, an approach should be adopted consistent with the Office of Environment and Heritage NSW Adaptive Management Position Statement (Office of Environment and Heritage NSW 2018b).
- Setting targets for project outcomes and annual outcome evaluation. If the results of the action are outside the target range, this triggers a review of the action. Project evaluation is based on benefits, likelihood of success of the project and cost.
- The importance of reporting outcomes to the NSW Government and the wider community and entering data into an appropriate database. For example, *Saving our Species* uses ‘species annual report cards’ and a traffic light reporting framework (ranging from a dark green light that indicates the annual target has been met, to a red light to indicate the annual target was not met). For projects initiated under the Strategy, there is a commitment for data to be made publicly available through the Sharing and Enabling Environmental Data (SEED) portal.

Although the MER Guidelines were written for *Saving our Species* conservation projects, they are transferrable to a range of action-based projects and provide a rigorous and robust assessment of outcomes of koala conservation actions. All agencies involved in delivering koala conservation and management actions in NSW will conduct their own MER for their projects, and we recommend that they adopt the MER Guidelines if they do not currently have an effective organisational MER document.

The Koala Strategy Evaluation Framework, which was developed to measure the achievement of the Strategy’s objectives and outcomes, is also a useful source of reference to align monitoring and evaluation activities and minimise duplication of efforts, where possible.

9.4 Synthesis of results

The Science, Economics and Insights Division has a role in the synthesis and interpretation of projects and actions carried out across the state. A database of projects will be created so that projects with similar aims can be compared. For example, if the aim is to reduce vehicle strike, the effectiveness of actions such as fencing, road signs and culverts could be assessed to build a statewide picture and provide recommendations for ongoing management.

10. Implementation

10.1 Organisational structure and governance

Effective leadership (scientific and management) is essential to keeping long-term programs going, including obtaining funding and good project management (Lindenmayer and Likens 2018).

NSW Department of Planning, Industry and Environment, Science, Economics and Insights Division has overall responsibility for project management, coordination, analysis and synthesis of koala monitoring programs under the Koala Monitoring Framework (the Framework). A NSW Koala Monitoring Expert Panel (the Panel), including internal and external reviewers has been established to review recommendations for local site inclusion, assess monitoring data against sampling objectives and review the Framework (see sections below). The Panel aims to have representation from members with professional experience or expertise in relevant fields, including long-term monitoring; koala ecology; modelling, statistics and analysis; genetics; disease and epidemiology. External scientific experts would be auxiliary members of the Panel and provide high-level advice on the direction of specialised fields such as genetics and ensure the most contemporary methods and practice are being used. The role of the Panel would be guided by a detailed terms of reference.

The Framework is long-term and encompasses a wide area. It is important that it is coordinated across all stakeholder groups to ensure consistency and quality of design, data collection, reporting, analysis and data storage. Activities will be integrated across sites with clearly defined overall responsibility and consistent sampling methodologies (Woinarski 2018).

Figure 3 gives an overview of the interactions among the partners involved in implementing the Framework.

10.2 Collaboration with monitoring partners

The Framework advocates building on, and collaborating with, existing koala monitoring programs across the state. This makes the best use of local knowledge, expertise, monitoring history and community support and provides greater efficiency and cost-effectiveness. This is also the approach most likely to ensure ongoing, long-term monitoring.

Collaborations should involve:

- An initial assessment of the program for inclusion in monitoring under the Framework by the Panel (section 8), including feedback and recommendations, if required.
- Agreements with monitoring partners, which detail roles and responsibilities, data sharing, analysis of data, evaluation of results, reporting, publication of results and communications.
- Where applicable, funding agreements, detailing project aims, methods and reporting requirements. Periodically, funding may become available to assist monitoring partners to make improvements to their current programs or expand them to include, for example, scat surveys for disease monitoring.

Opportunities for encouraging collaboration and sharing of data across the monitoring and research community should be explored as implementation of the Framework progresses.

For example, research grant agreements under the NSW Koala Strategy (the Strategy) Koala Research Plan have special conditions that currently include:

38. Research should endeavour to align with the principles and practice of open science: open access, open data and open source. Data will be required to be entered into SEED (the Sharing and Enabling Environmental Data portal, www.seed.nsw.gov.au).

39. Any koala tissue samples collected as part of the research must be accessioned to the biobank at the Australian Museum, prior to the end of the research and prior to receiving the final payment.

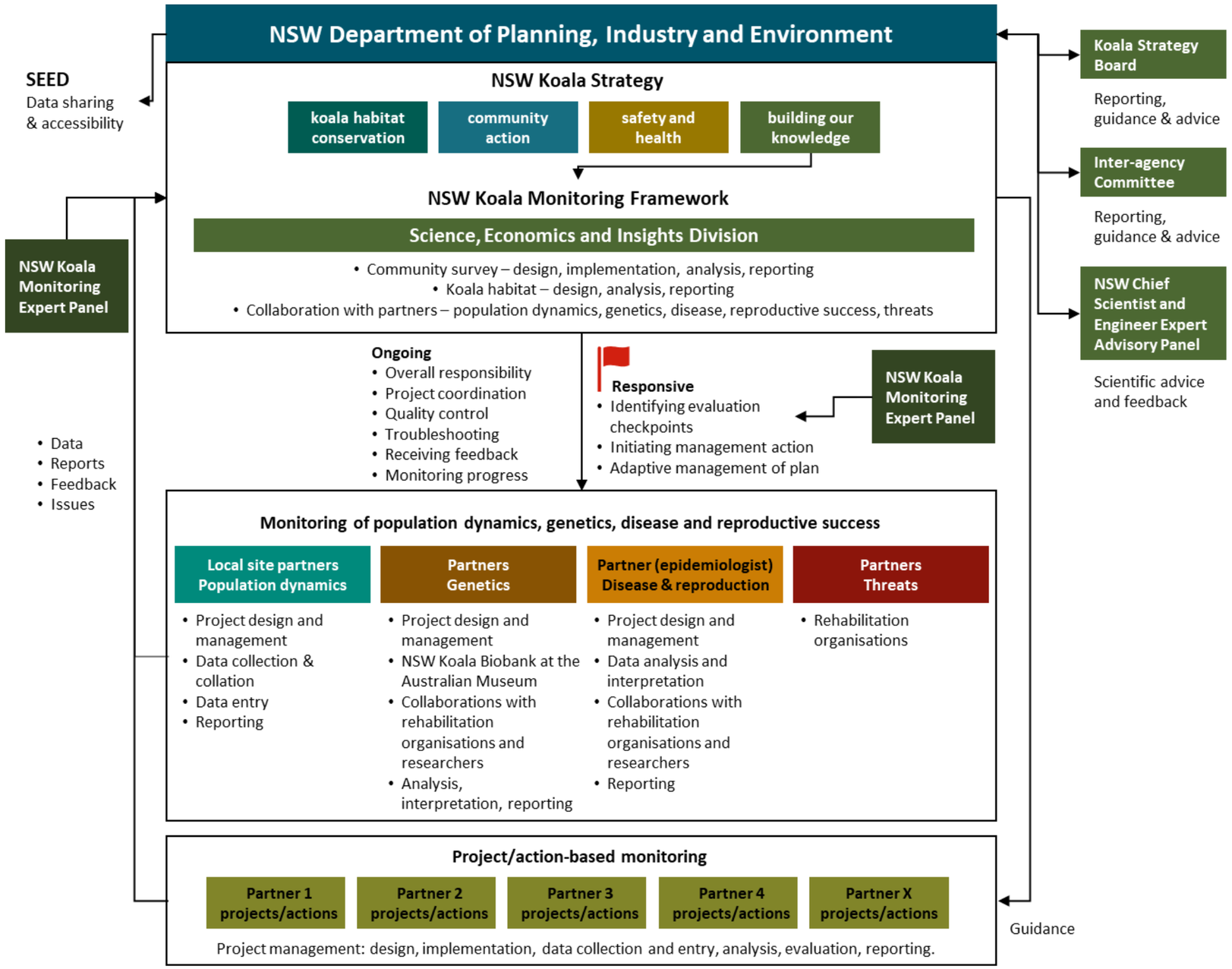

Figure 3 **Organisational structure of the NSW Koala Monitoring Framework showing the relationships between stakeholders involved in its implementation. It includes government departments, advisory bodies and monitoring partners. The roles and responsibilities of each stakeholder are detailed, and the flow of guidance, data, reporting and advice are indicated by the arrows.**

10.3 Data quality assurance, management and storage

10.3.1 Quality assurance

Assessment for inclusion

Sites should be assessed for inclusion in the Framework, which includes an assessment of design and methods based on specific criteria, adapted from Woinarski (2018), which ensure a robust sampling design and effective local-scale monitoring (section 8). Feedback will be provided and, where required, improvements to monitoring will be agreed upon.

Consistency and standardisation

Consistency in collection of data and analysis of samples is important to enable comparison of monitoring data and to give us the ability to conduct meta-analysis and synthesis of data across the state.

The Framework involves building partnerships and data sharing with monitoring programs across the state, and as a result, the methods used to survey koalas will differ (see discussion in section 3.3.2). However, for a method to be suitable for monitoring, it would: (i) be fit-for-purpose; (ii) have previously been used in a monitoring or survey context; (iii) include an estimate of detectability; (iv) have been researched to gain an understanding of its advantages and limitations; and (v) have been subject to peer review through publication in a scientific journal. Individual survey methods (e.g. SAT scat surveys) should be applied consistently across sites and guidelines provided to monitoring partners. We should also develop methods to compare population trends among the different sites across the state, using appropriate statistical methods that can analyse trend data collected using different survey methods (e.g. scat and acoustic surveys).

Consistency in collection of samples (e.g. tissue, scat) and analysis methods are addressed in the Genetics (section 5.4) and Disease (section 6.2.2) sections. Collection of samples under the Framework should comply with the methods outlined in these sections (i.e. Australian Museum instructions for sample collection in the Code of Practice for Injured, Sick and Orphaned Koalas (Office of Environment and Heritage NSW 2018c) and Koala Health Hub sampling protocols (Koala Health Hub 2019). Experts in genetics and disease on the Panel should be consulted on the most appropriate analysis techniques to use and this information passed on to our monitoring partners.

Adaptive monitoring

New technologies and methods will evolve over time. The aim is to gather data that will have the ability to talk to each other, whilst allowing new innovations, methods and technologies to be incorporated (see Box 1, section 2 for details).

10.3.2 Data management and storage

Good data management of long-term monitoring across NSW starts with effective communication with agencies and partners. The NSW Department of Planning, Industry and Environment (the Department) Science, Economics and Insights Division should have an active role in collating and managing data from all projects to enable this information to be used at a statewide scale and analysed in relation to broader population and habitat monitoring.

The Framework follows the NSW Koala Data Strategy. An overarching data management plan has been created from the template developed as part of the Koala Data Strategy (Figure 4). Individual data management plans should be created for each of the monitoring projects associated with the Framework. Raw data should be collected/compiled annually, validated, and then stored and made publicly available through NSW BioNet or maintained in private institutional databases (e.g. universities, non-government organisations).

Preferably, all data should be linked to the SEED portal to enable access, sharing of data among organisations, and contribution to the larger database of environmental data. Data owned by separate research projects and shared with the Department for monitoring purposes should be maintained in private databases until published or in accordance with the owner's policies. Genetic samples and data will be stored in the NSW Koala Biobank at the Australian Museum, where they can be accessed for koala monitoring by the Australian Museum or other scientific researchers, and the wider scientific community.

Both internal and external researchers must ensure that data is made available for the purpose of the Framework within a month of collection so that it can be incorporated into the adaptive management approach of the Strategy. Researchers must also publish their data in a timely manner as detailed in section 10.6.

Results, in the form of reports and publications, should be provided to the Department as per agreements with the partners involved. These would be made available through the Framework project in SEED.

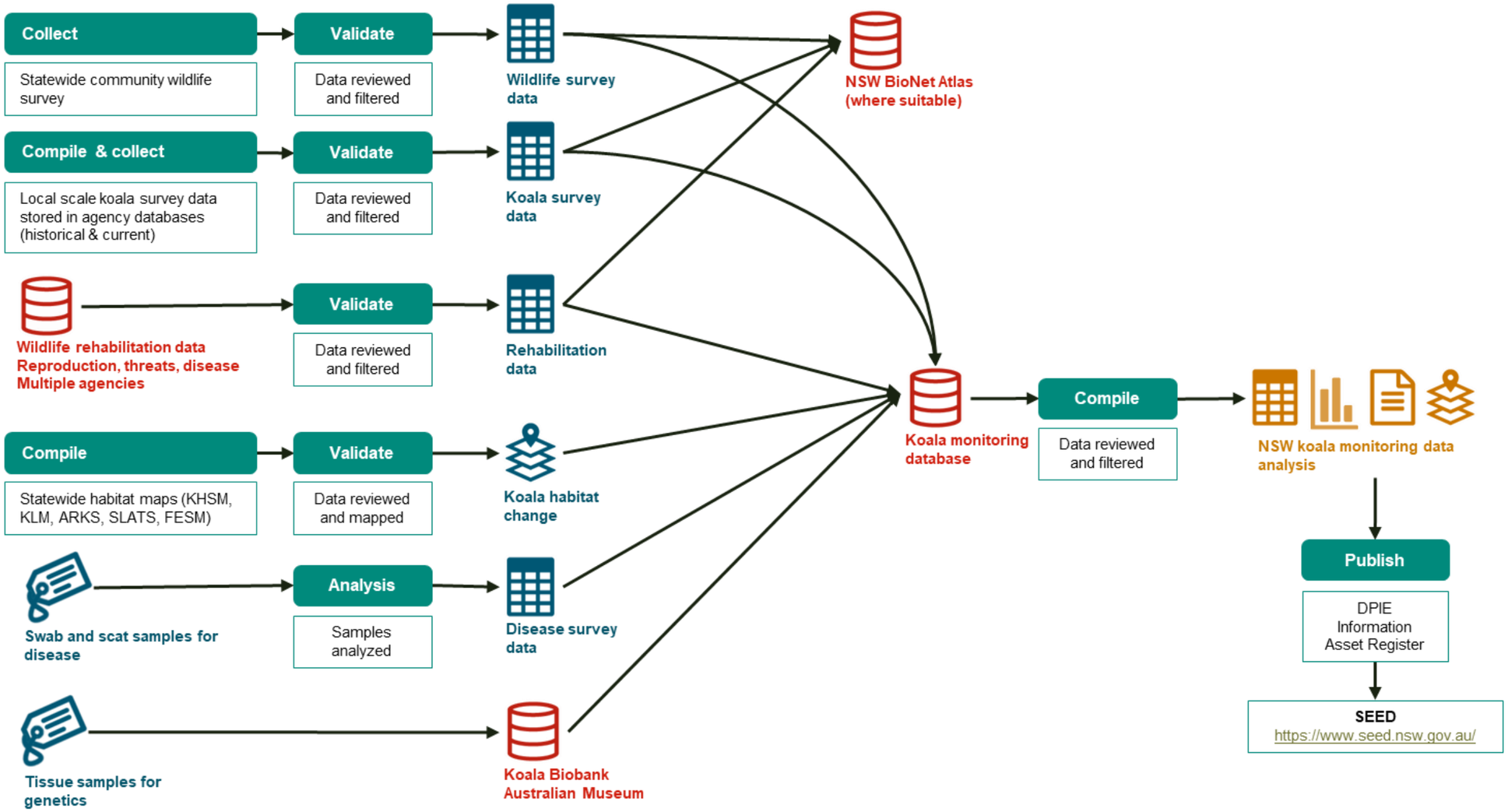

Figure 4 **NSW Koala Monitoring Framework Data Management Plan.**
DPIE = Department of Planning, Industry and Environment, SEED = Sharing and Enabling Environmental Data portal

10.4 Data evaluation and use

There are many examples of species that were monitored until they went extinct due to a lack of action when their population reached a critical point (Lindenmayer and Likens 2018). Further, as populations fluctuate naturally over time, it can be challenging to distinguish changes that are cause for concern. Thus, it is important to regularly review the monitoring data to ensure that action is timely, and the results are available for management purposes.

10.4.1 Data evaluation

In this Framework, sampling objectives have been set in each section with ecologically meaningful points that require action. These points may indicate undesirable changes such as declines in occupancy, but could also indicate positive outcomes such as increases in koala habitat due to land purchases.

The sampling objectives are phrased in two ways:

- A significant change. For example, ' …the sampling objective of threat monitoring is to detect a significant change in the relative proportion of threats at a site between sampling intervals'.
- As a decision trigger (Freegard and Williams 2009). For example, ' …a decision trigger is activated if there is a 20% change in the population of koalas at the regional or statewide level between surveys.' The steps in this process are shown in Figure 5, adapted from de Bie et al. (2018).

The frequency of evaluation of trends is given in the data evaluation subsection in each section of the Framework. Our monitoring partners should provide data to the Science, Economics and Insights Division in accordance with the periodicity of their programs (section 10.3.2), ideally accompanied by their analyses and interpretation of the data. Science, Economics and Insights Division should also support partners who do not have the capacity to do statistical analysis and conduct meta-analyses. When a sampling objective is reached, it will need to be assessed by the Panel, and a recommendation for action will be presented to the Department's Koala Strategy Board. When a serious or rapid change is detected, for example, *Chlamydia pecorum* is detected in a naïve population, an immediate response would be put in place. An extraordinary meeting of the Panel would be called so that action (e.g. a vaccination program) could be implemented as soon as practicable.

In addition:

- a report summarising all monitoring data should be prepared every two years by Science, Economics and Insights Division. It should include interpretation of the data by our on-ground monitoring partners as well as graphical and statistical analysis by Science, Economics and Insights Division and/or our partners. This report should be reviewed by the Panel
- the monitoring data, as well as any actions resulting from the data evaluation, should be presented at the Koala Research Plan Symposium every 2 years for wider scientific peer review and critique
- there will be a dashboard, updated every year, and a more comprehensive report every 5 years (see section 10.6).

Managers, scientists and agencies/partners should be involved in the interpretation of monitoring results at these intervals and in making recommendations for appropriate actions by decision makers (Holthausen et al. 2005).

Regular evaluations enable reflection on whether the sampling objectives and decision triggers need to be revised, based on the data. Adaptive change to the Framework may be required as a more comprehensive understanding of koala population trends is developed.

10.4.2 Action

It is important to follow through with action, once decision triggers are met (Cook et al. 2016; Addison et al. 2016; de Bie et al. 2018). However, it is also important to distinguish true declines from fluctuations. The Threatened Species Scientific Committee, NSW Threatened Species Scientific Committee and the International Union for Conservation of Nature (IUCN) have set the lowest threshold for a declining population as 30% reduction over three generations to differentiate fluctuations from reductions (IUCN Criterion A: Declining population). The downward phase of a fluctuation does not normally count as a reduction (IUCN Standards and Petitions Subcommittee 2017). Furthermore, a population reduction relates not only to the size of the change, but also the capacity of the koalas to recover (Department of Sustainability, Environment, Water, Population and Communities 2011). That is, if a decrease in population is due to a natural process from which koalas are expected to recover, action will be different from the action required for a decrease due to a permanent change in habitat availability or climate.

Examples of actions that may be required when decision triggers are met include the following:

- Research local threats and possible causes of the decline. For example, a new residential development may have resulted in a portion of the site being cleared, a severe drought or bushfire may have occurred, etc. Local community groups are good sources of information.
- If there are no obvious local causes, conduct a more detailed investigation of threats, for example:
    - compare population dynamics data to population health data to determine if disease may be the cause
    - discuss with local carers and wildlife hospitals to determine whether there has been an increase in dog attacks or vehicle strike
    - conduct a site visit to determine health of the habitat.
- If a fluctuation is considered likely, practice watchful waiting for another year.

10.4.3 Data use

The data generated from koala monitoring programs under the Framework will feed into the adaptive management process of the Strategy (Office of Environment and Heritage NSW 2018a). It will contribute to evaluation of the success of management actions in achieving the long-term goal of the Strategy to stabilise and then increase koala numbers and ensure genetically diverse and viable populations across the state. The cyclical nature of the adaptive management process allows modification of actions if objectives are not being met, so that they provide better conservation outcomes for koalas.

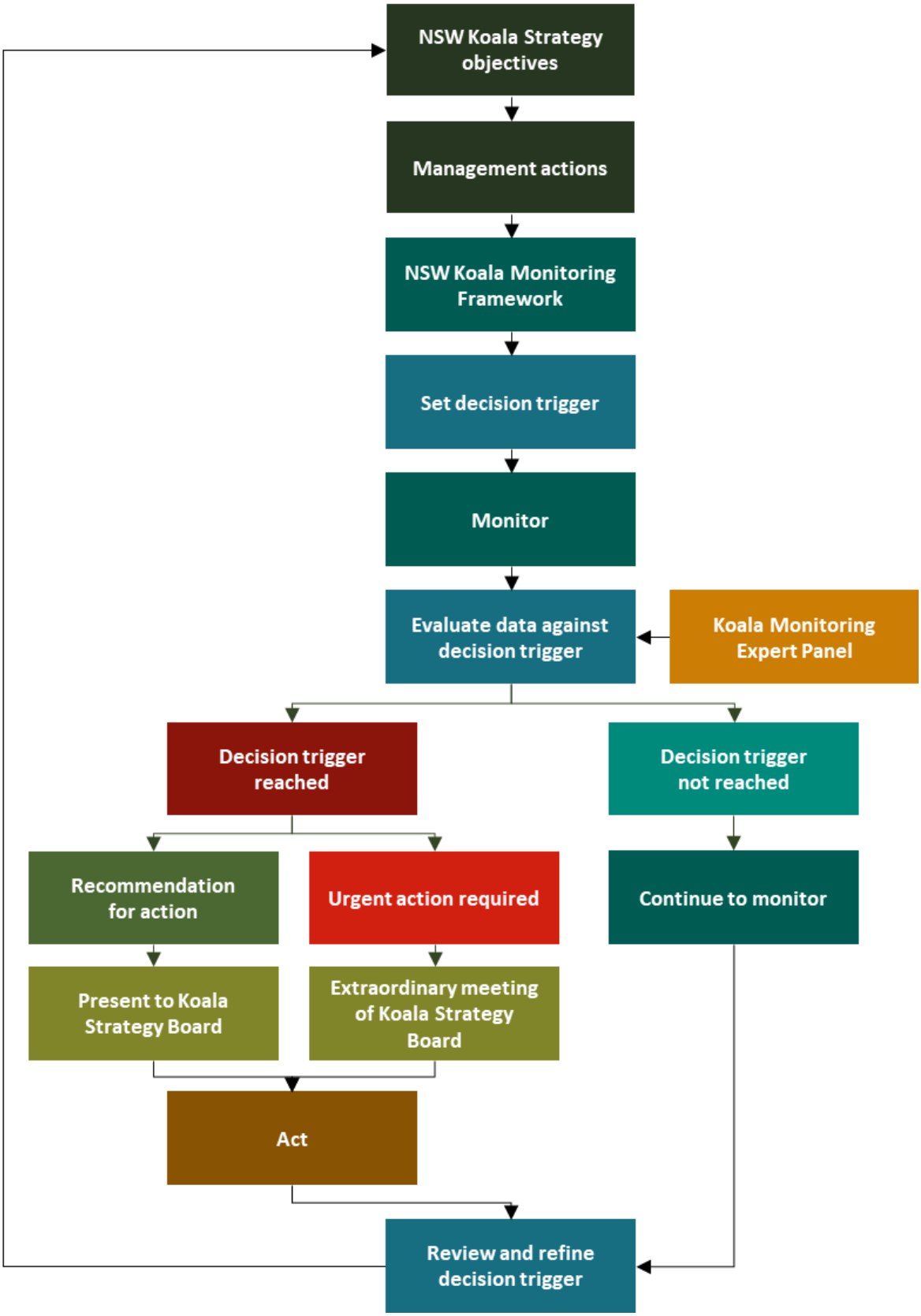

Figure 5 **The process of integrating decision triggers into data analysis for management**

10.5 Review and evaluation of the Framework

The need for a review process is essential to ensure that data quality standards are met and that monitoring funds are being used effectively (Holthausen et al. 2005). A full review of the Framework involving the Panel and all agencies will be done at 3 years. Subsequent reviews will be done every 3 years. These reviews will be guided by the 'framework for evaluating the adequacy of monitoring plans for threatened species' (Woinarski 2018). An initial evaluation against the framework is shown in Table 4.

The review and evaluation will consider:

- aims and objectives
- appropriateness of the methods and survey design (for example, was there enough power to detect change over time) and whether adaptive monitoring is required
- dissemination of the results in alignment with the Strategy's Communication Plan (e.g. to researchers, the community)
- availability/sharing of data generated.

The results of the evaluation will be made publicly available.

Table 4: Framework for evaluating the adequacy of monitoring programs for threatened species

Metric	Score (current) out of 5	Target score (with Framework)	Score basis
1. Fit-for-purpose	3	4	One or more reliable methods
2. Coverage	3	4–5	Many sites across range
3. Sampling periodicity	2	3–5	Monitoring annually
4. Longevity	1	2–3	10+ years, ongoing commitment
5. Design quality	1	4–5	Statistical power to detect small (e.g. 5%) to moderate (30%) change in population
6. Coordination	1	4–5	Tightly integrated across sites with overall responsibility and consistent sampling methodologies
7. Data availability and reporting	2	4–5	Data readily accessible
8. Management linkage	1	5	Adaptive management, triggers and review
9. Demographic parameters	1	3–5	Includes information on relevant life history parameters
Total Score	**15**	**33–42**	**/45**

Note: Scores range from 0 = least good to 5 = most adequate. For full details of the basis of each score for each metric see Woinarski (2018).

10.6 Communications

‘Communication is the responsibility of all monitoring practitioners, from first discussions with land managers, landowners and decision-makers, to evaluating and sharing results, to reporting on conservation outcomes. Good communication will help to ensure continuing support from all stakeholders and to justify future resource allocation.’

(Legge et al. 2019)

Communication is an important element of koala monitoring programs under the Framework. It is vital to regularly engage with and update stakeholders and the wider community on monitoring outcomes across the state. Throughout the lifespan of a koala monitoring program based on the Framework, communications should include:

- **Regular updates to the wider community –** Updates in the form of partner profiles, articles and news items that target a range of sectors of the community should be published on the Department’s Environment, Energy and Science website and on social media. Examples include:
    - profiles of each of the koala monitoring programs run by our partners, including an overview of the program, details of the specific local site and team, the monitoring design and methods, results and recent news
    - updates on milestones achieved, such as sections of the monitoring program that have recently been implemented
    - news items in the form of articles about upcoming citizen science opportunities (e.g. the community wildlife survey) and community koala monitoring events such as the Narrandera Koala Count (NSW Department of Planning, Industry and Environment 2019e)
    - media releases and newsletters sharing recent findings, community actions underway and project updates, such as the South Coast Koala Conservation Project (NSW Department of Planning, Industry and Environment 2018a).
- **Reporting –** Regular, transparent reporting to the NSW Government and the community enables monitoring information to be used for management and conservation of koalas in an ongoing way, where and when it is needed. Reporting should include:
    - a dashboard, updated every year, which details trends in koala populations
    - a full report, which includes analysis and interpretation of findings, and recommendations for action, produced at 5 years.
- **Peer-reviewed publications –** In addition to a dashboard, reports and monitoring data, and information available through the SEED portal, scientific papers should be published in peer-reviewed journals to ensure long-term accessibility of monitoring trend data, its interpretation and implications. External research collaborators must publish their data in a timely manner (within 3 years of the conclusion of their project) to ensure that data is disseminated and can be incorporated into the adaptive management strategies.

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