Koala Research Centre
of Central Queensland

Conserving Central Queensland's Koalas

Edited by Dr Nicole Flint and Dr Alistair Melzer

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CQUniversity AUSTRALIA RESEARCH

CONSERVING CENTRAL QUEENSLAND'S KOALAS

Edited by Dr Nicole Flint and Dr Alistair Melzer

Koala Research Centre of Central Queensland

CQUniversity Australia

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Nicole Flint and Alistair Melzer (Editors)

Contributing Institutions

San Diego Zoo Global

San Diego Zoo Global is a conservation organisation dedicated to the science of saving endangered species worldwide. San Diego Zoo Global operates the San Diego Zoo, the San Diego Zoo Safari Park, and the San Diego Zoo Institute for Conservation Research. Conservation work takes place locally at these three campuses and reaches beyond to more than 100 conservation field projects in 35 countries. To date the program has reintroduced 33 species back into the wild including: mountain yellow-legged frogs, 5 species of reptiles, 17 species of birds, and 10 species of mammals; and has been instrumental in helping to increase the number of giant pandas at China's Wolong Breeding Center from 25 bears to more than 100. Major contributions have been made to saving the California condor from extinction, helping to increase the population from only 22 birds to more than 300, and releasing the first birds back to the wild in Baja California, Mexico. Collaborating with the U.S. Navy, the San Clemente loggerhead shrike project has helped repopulate this songbird from just 14 birds to more than 70. San Diego Zoo Global's Koala Education & Conservation Program, first implemented in 1983, reaches a global public through exhibition, education and research programs. This program generates funds to support in-situ conservation and research initiatives.

CQUniversity

Koala Research Centre of Central Queensland (KRC)
The Koala Research Centre of Central Queensland is a community funded research group at CQUniversity. The KRC has been pursuing regional koala research since the mid-1990's and maintains coastal and western long-term research sites across central Queensland in conjunction with the regional community as well as national and international colleagues. The KRC was an initiative of the Rockhampton City Council and is guided by a community advisory board including Rockhampton Regional Council, Central Queensland Koala Volunteers, Koala Conservation and Wildlife Management Strategy (Queensland Department of Environment and Heritage Protection), and CQUniversity.

Centre for Environmental Management (CEM)
The Centre works in association with Government, Industry and other stakeholders to understand and facilitate sustainable environmental management.CEM focuses on issues of sustainable regional development, environmental accounting, biodiversity management, rehabilitation success, and ecosystem functional indicators of environmental performance and integrated regional monitoring.

Queensland Parks and Wildlife Service (QPWS)

Koala Policy and Operations Branch, Brisbane
The QPWS is an entity of the Department of Environment and Resource Management (DERM), which protects Queensland's biodiversity and the natural environment and its resources. The QPWS Koala Policy and Operations Branch includes the Koala Strategy and Policy Unit and the Koala Operations Unit. Its role is to progress key elements of the Queensland Government Koala Response Strategy, including the:

- Disease Research Grant program to support high quality research into mitigating the effects of disease on wild populations of koalas;
- implementation of state planning instruments and associated policies relating to koalas;
- koala habitat protection and rehabilitation plan;
- koala survey and monitoring plan; and
- South East Queensland Local Government monitoring and reporting framework to review koala conservation strategies.

The Ecological Assessment Unit
The Ecological Assessment Unit pursues projects that address prioritised knowledge gaps, evaluate the effectiveness of on-ground management actions and inform/promote sound management decisions. Further the unit provides professional and technical knowledge and support to QPWS regions and field staff, including through training and mentoring, to build capacity and promote effective and efficient on-ground management – particularly in the areas of fire, pest and biosecurity management on terrestrial and marine estate. The Ecological Assessment Unit also develops simple, standardised methodologies for park staff to evaluate the outcomes of management activities on estate so that future decisions and management actions are based on evidence and made in an adaptive, accountable management framework.

Planning and Program Delivery Branch, Conservation Strategy and Planning, Rockhampton
The Planning Unit is responsible for developing management plans and associated documents for the protected area estate across the central portion of Queensland. This involved engagement with managers at all levels within QPWS as well as a wide range of stakeholder groups. They have made a significant contribution to the development of the State Management Evaluation Effectiveness Framework.

The University of Queensland (UQ)

Landscape Ecology and Conservation Group
The Landscape Ecology and Conservation Group works across a range of temporal and spatial scales and utilise a variety of methods including field surveys, remote sensing and geographic information systems (GIS), and ecological and spatial modelling to address the following areas of interest:

- Conservation in human-modified landscapes. This research aims to understand the consequences of human modification of landscapes for biodiversity conservation.
- Climate change, landscape change and biodiversity. Through this research, linkages between climate and landscape/land use change and biodiversity are explored.
- Landscape systems. This research explores landscape systems and the consequences for sustainable land management.

Centre for Mining Land Rehabilitation (CMLR)
The CMLR is a research centre that builds on the strengths of the diversity of backgrounds and disciplines of its staff and postgraduate students to address the environmental challenges of the minerals industry with quality science. CMLR works closely with industry, governments and communities, to translate research outcomes into practices that will lead to the continual improvement of rehabilitation and environmental outcomes for a sustainable future.

Wildlife Biology Unit, School of Agriculture and Food Sciences
The School of Agriculture and Food Sciences is committed to finding solutions to global issues related to diminishing natural resources, climate change and feeding a growing population. The School has a commitment to whole animal biology and applied ecology. Research focused on vulnerable native species (wild and urban) is leading to their better protection and management through studies of fundamental anatomy and physiology, behavioural ecology, the impact of pest species and the development of innovative captive breeding programs.

Griffith University

Applied Road Ecology Group
The Applied Road Ecology Group is based in Griffith University's Environmental Futures Centre. Led by Associate Professor Darryl Jones, and consisting of six associates, the group has been involved in a wide variety of road ecology projects, most notably in long-term monitoring of fauna use of the Compton Road Fauna Movements Array. Since 2004, numerous consultancies have been undertaken including for Brisbane City Council, Redlands City Council and several environmental consultants. To date the biggest and most ambitious project is the 'Koala Monitoring and Retrofit' project for the

Queensland Department of Transport and Main Roads. This is the first detailed investigation of the movements and behaviour of koalas with respect to roads and includes a particular focus on their use of crossing structures including the world's first koala overpass.

Australia Zoo

The Australia Zoo Wildlife Hospital is located on the Sunshine Coast (Beerwah). Four full-time veterinarians and 13 vet nurses work a 24 hr roster, 365 days/year to treat and rehabilitate injured, sick, and orphaned Australian native wildlife. Approximately 1000 wild koalas were treated at the zoo last year (2011). The wildlife hospital has a holding capacity of about 90 koalas at all time. It also treats birds, reptiles, sea turtles, macropods, possums, bats, gliders and other wildlife species.

Dreamworld Australia

Dreamworld's Australian Wildlife Experience, on the Gold Coast, is one of the largest native wildlife parks in South East Queensland with 100's of native animals, including the second largest captive koala population. Koala Land is a recent project, commissioned by the General Manager of Life Sciences, Dreamworld Australia. This project aimed to make recommendations for protecting koalas and koala habitats, establish and illustrate what is needed to maintain existing koala habitats and to rethink sustainable environments where humans and koalas can live side by side.

Leading this project was Mark Gerada, an Australian artist, designer and teacher with a background in architecture, planning, publishing and advertising. Mark currently teaches Visual Communications in the Faculty of Design Architecture and Building, University of Technology Sydney. His emphasis is on the communication of complex ideas in a succinct fashion and developing distinctive identities and branding for socially responsible campaigns.

Contents

Contributing Institutions i

Preface. 1

A pathway to koala conservation in central Queensland 1

Introduction. 4

National perspective on the current status of koalas: Setting the scene for central Queensland koala conservation 4

Theme 1. REGIONAL RESEARCH AND MONITORING OF KOALAS AND THEIR HABITAT. 11

Regional research: perspectives from the field in central Queensland 11
The Koala Venture Research Partnership: an overview of 24 years of regional koala research in central Queensland 16
Overview of Koala Research Centre study sites 20
WORKSHOP SESSION 1: Effective monitoring of koalas and habitat in central Queensland 24

Theme 2. CENTRAL QUEENSLAND'S KOALA ISLANDS 25

Managing Central Queensland's Koala Islands 25
Is killing goats and burning bush the answer? 29
Visions of the future: management plans 37
WORKSHOP SESSION 2: Planning and management of koala habitat on Central Queensland islands 40

Theme 3. CAPTIVE MANAGEMENT AND KOALA CONSERVATION 41

Koala management and research at the San Diego Zoo 41
Overview of the captive koala population based in Zoo and Aquarium Association institutions and Dreamworld's perspective on koala conservation 48
The role of captive koalas in koala conservation 54
WORKSHOP SESSION 3: Captive management in global koala conservation (local, national and international refuges for koala genotypes) 60

Theme 4. DISEASE AND KOALA ECOLOGY 61

Disease and ecology in central Queensland 61
Zoo based conservation: collection-driven koala health research 70
Landscape change and disease in Queensland koalas 75
WORKSHOP SESSION 4: Role of disease (including koala retrovirus (KoRV) and Chlamydia) in koala ecology and importance for conservation planning 85

Theme 5. DROUGHT AND THE KOALA – A REGIONAL PERSPECTIVE 86

Changes in koala distribution and numbers in south west Queensland, 1995-2009 86
Koala reproduction and the effect of drought in central Queensland; lessons from the Koala Venture project 91
Drought and the koala: two case studies from the central highlands 95
WORKSHOP SESSION 5: Conceptualising drought responses at a local and landscape level 100

Theme 6. KOALAS, HIGHWAYS AND ROLLING INFRASTRUCTURE 101

Koalas and roads: a case study in Ballarat, Victoria 101
Understanding the movements of koalas in a road-dominated landscape 106
What do we know about CQ koalas near rolling infrastructure? 111
WORKSHOP SESSION 6: Central Queensland highway and infrastructure corridors 115

Theme 7. REGIONAL PLANNING FOR THE CENTRAL QUEENSLAND KOALA 116

South East Queensland Koala State Planning Instruments 116
Koala Land: koala research collaboration project 121
Koalas and climate change: priority koala conservation areas for central Queensland 124

Regional planning for central Queensland koalas: a framework for planning 130
WORKSHOP SESSION 7: Regional planning for conservation alongside resource extraction, urban expansion and rural enterprises 134
Theme 8. RECOVERING KOALA HABITAT 135
Recovering koala habitat... 135
The Koala Venture Partnership: Habitat clearing and restoration 138
Restoring riparian koala habitat – Springsure Queensland 143
WORKSHOP SESSION 8: Restoring koala habitat and scenarios for population recovery 144

Preface.

A pathway to koala conservation in central Queensland

Dr Alistair Melzer[1], Dr William Ellis[1,2] and Dr Sean FitzGibbon[2]

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[2] *Centre for Mined Land Rehabilitation, The University of Queensland Brisbane, Queensland 4072, Australia*

The koala is an international icon that, along with the panda, induces a strong emotional response among people of many cultures. In Australia it sits alongside a few other native mammals (the generic kangaroo, echidna, platypus and wombat) as well as several birds (kookaburra, emu and magpie) that contribute to our sense of place – of the Australian bush and the unique wildlife that inhabits it. For well over a century, money, effort and emotional resources have been directed to the preservation or management of the koala. The financial cost has been high in South Australia and Victoria where translocation programs and intensive management regimes are in place. In coastal New South Wales and, most recently, in south eastern Queensland, a similar pattern of high-cost intervention is developing in the wake of alarming data describing population declines. The focus of this investment in Queensland has been the attempt to mitigate injury or distress to individual animals or local populations – care for sick and injured animals and protecting individual koalas from the impacts of clearing for development: the geographical focus of this investment has been the south east corner of the state.

There is a paucity of regional or even local success stories about protecting koala populations, and the general consensus among koala researchers, managers and animal carers is that the species is in decline or under threat throughout much of its range. So, despite the long history of intense public concern and institutional investment, efforts to conserve the koala have failed to halt the decline. This failure has been highlighted, most recently, by the Australian federal government's classification of the koala as "vulnerable" in New South Wales, the Australian Capital Territory and Queensland.

In February 2012 an expert workshop was convened to assist in developing a strategy for the conservation of the koala in central Queensland. The multi-disciplinary workshop assemblage included – from the academic research community: the Koala Research Centre of Central Queensland at CQUniversity; the School of Agriculture and Food Sciences, the Centre for Mined Land Rehabilitation, and the Centre for Spatial Environmental Research at the University of Queensland; the Applied Road Ecology Group at Griffith University; from the captive koala research and captive management sector: San Diego Zoo Global, Australia Zoo Wildlife Hospital, Dreamworld and the Rockhampton Zoo; from the regulatory and conservation management sector in the Queensland Government: Koala Policy and Operations Branch, Sustainable Landscapes, Queensland Parks and Wildlife Service; the Ecological Assessment Unit and the Planning Unit, Queensland Parks and Wildlife Service, Department of Environment and Resource Management; and the Department of Transport and Main Roads. [*Note: the government departments named here and throughout this book were current at the time of the workshop (1-3 February 2012) Eds*].

The contributions to that workshop form the chapters in this book. From these contributions and the associated workshop sessions we have concluded that, in central Queensland at least, a proactive bioregional approach to conservation is required.

A regional network of sentinel sites is required to gather critical knowledge on trends in koala population and habitat condition. Ideally the sites would be established across the extent of the koala's range in key habitat types. Semi-autonomous data loggers could be deployed to record environmental and bio-acoustic parameters. A periodic census at some agreed frequency would provide data on trends in population size and demography. Trends in habitat structure and condition could be monitored at permanent plots and linked with remotely sensed imagery. The costs may be offset if the sites also provide reference data for other environmental purposes such as in post-mining restoration.

It is expected that there are key refugia in the landscape that have allowed populations to persist through periods of adverse environmental conditions. It has been proposed that Minerva Hills, Blackdown Tableland, Kroombit Tops as well as the Connors and Clarke Ranges at least provide such refuge. Modelling suggests that conserving such refugia will be important in the persistence of koalas and their habitat in the face of intensifying climate change impacts. A regional assessment, with the assistance of suitable bioclimatic modelling, is required to identify the regional refugia. Regional conservation planning needs to be founded on the refugia.

Regional conservation planning requires recognition of three basic zones each of which has characteristic anthropogenic drivers of decline in koala habitat and associated populations. These are:

1) Coastal and peri-urban zone where the pressures are associated with increasing human populations and associated intensification of infrastructure;

2) Mining and industrial zone with intense landscape disturbance and intensifying infrastructure development; and

3) Rural zone where the pressures are derived from agricultural practices.

Given that there is no immediate likelihood of any curtailing of human population growth or limiting of resource extraction the management focus needs to be on preservation in the coastal and peri-urban zone and preservation and post-mining restoration in the mining and industrial zone. Only in the rural zone are there any meaningful opportunities for successful and proactive conservation planning. In central Queensland this is by far the largest zone, populated by many important stakeholders who will need to be engaged if effective conservation outcomes are to be achieved.

At the local level koala conservation plans need to be developed and implemented within existing conservation tenures. This is important given the highly fragmented landscape across central Queensland and, consequently, the vulnerability of local populations to stochastic events and to inappropriate management actions. This vulnerability applies to the koala islands (St Bees, Brampton and Rabbit/Newry islands as well as Magnetic Island), mainland state conservation tenure (including state forests and timber reserves) and Commonwealth lands (Shoalwater Bay Military Training Area).

Zoos are seen to be critical in carrying the conservation message to the local, national and international community. As such it is essential that each zoo has a vision that incorporates the captive koalas in conservation actions for the species. However, some review of the integrity of koala populations held in captivity may be required to consider how effectively the captive animals represent the local koala genotype.

It is evident that raised conservation classifications at the State level, together with local planning tools and environmental regulation have not halted the koala's decline. It seems unlikely that the recent Federal "vulnerable" classification for the koala will, of itself, alter the koala's decline. A new approach is required to effectively conserve not only the koala and its habitat but also many other ecosystem elements. We propose tripartite associations among government, corporations and the community. In this association government provides regulation and incentive, corporations provide resources and logistical support and the community provides expertise (research, planning) and on ground implementation. We would, for example, envisage rural landholders receiving funds and resources to manage koala populations and improve koala habitat as part of working rural enterprises, non-government organizations being resourced to work alongside state conservation managers in parks and other conservation tenures, and regional researchers supported to undertake targeted conservation research and monitoring.

We hope that this volume provides a better understanding of the conservation issues around central Queensland's regional koala populations and stimulates action that results in effective research and management.

Introduction.

National perspective on the current status of koalas: Setting the scene for central Queensland koala conservation

***Prof Frank N Carrick* AM**

Historical context

When the first Aboriginal people arrived in what is now Australia, koalas were living in parts of all of what are now the mainland states, but interestingly there is no trace of koalas ever having been in Tasmania (apart from the present zoo population). From then on it has been more-or-less downhill for koalas!

At the time of European occupation, koalas had become extinct in Western Australia around 50,000 to 60,000 years previously – probably due primarily to climate change but perhaps exacerbated by human-induced environmental modification (does this sound vaguely familiar?).

Sometime between World Wars 1 and 2, koalas became extinct in South Australia – largely due to human activities. Extinction also came pretty close in mainland Victoria and koalas were massively reduced in New South Wales in the late 19th and early 20th centuries due to a combination of habitat destruction and fragmentation, alteration of fire regimes, induced diseases and massive hunting for their fur; this suite of insults to the species' survival was also visited upon Queensland's koalas, but due to the different timing and relative scale of European occupation of the state, the impact on the species was somewhat less catastrophic.

The second half of the 20th century saw ongoing and even accelerating destruction of koala habitat (particularly in Queensland) and the secondary effects of this loss and fragmentation – regrettably this continues and is being exacerbated by the effects of climate change. Whether or not these dramatic changes in climatic patterns are due to anthropogenic factors is something of a moot point as far as the dwindling habitat of koalas is concerned – whatever the underlying causation, environmental change is happening – some western parts of the koalas' range are experiencing changes that have not occurred for at least half a millennium.

Contemporary situation

Now in the second decade of the 21st century, the recent Australian senate inquiry into the koala has assembled compelling evidence that the species is in serious trouble, but has emphasised that the threatening processes, ecology and knowledge of koalas are as patchy as the distribution of the species – 'one size' definitely does not 'fit all' situations or management requirements.

The Senate Standing Committees on Environment and Communications "Inquiry into the status, health and sustainability of Australia's koala population" in 2011 is probably the most comprehensive compilation of koala information since Sue Arnold of Australians for Animals' successful application (to which Alistair Melzer and I contributed) for the koala to be listed (in 2000) under the United States Endangered Species Act of 1973.

Based on evidence and submissions to the Senate inquiry and other sources, the present situation of Koalas throughout continental Australia (going anti-clockwise around the nation) can be summarised as:

- Western Australia – There are actually koalas back at Yanchep where Pleistocene fossils of their ancestors were discovered in a cave about 50 years ago – but these are 'ex pats' from the east and are essentially a zoo population.
- South Australia – All the present koalas in the State are also 'ex pats', though free-ranging. Due to their depauperate genetic origins, they make a very limited contribution to the evolutionary potential of the species and their issues are largely those of managing wildlife outside its natural range. These issues must not be allowed to interfere with conservation management of the populations endemic to eastern Australia, where descendants of elements of the koalas extant when Europeans arrived still remain.
- In eastern Australia where the remaining 'natural' populations exist, koala distribution is heterogeneous. The patchy distribution is partly the result of naturally patchy habitat, but has been considerably exacerbated by the extreme fragmentation caused by human destruction of habitat.

Whilst 'officially' there are three recognised subspecies of Koalas (*Phascolarctos cinereus adustus* in Queensland, *P. c. cinereus* in New South Wales and *P. c. victor* in Victoria [and now distributed extralimitally to South and Western Australia]), the reality is that there are two kinds of modern koalas: **Northern Koalas** – distributed from north Queensland to probably somewhere south of the New South Wales/Victorian border (*P. c. cinereus*) and **Southern Koalas** – distributed through most of Victoria and extralimitally in South Australia and captive populations (*P. c. victor*).

Northern koalas

The densest populations (even considering observer bias) of northern koalas occur in south east Queensland and north east New South Wales; unfortunately this coincides with the highest rate of ongoing development pressure. It is beyond doubt that koalas in south east Queensland and north east New South Wales are declining catastrophically and there is also clear evidence that the western populations of northern koalas are crashing due to unprecedented climatic impacts.

In New South Wales, the koala is almost extinct in the southern half of the state and in diabolical trouble in the north-eastern parts of its range; several populations are listed as 'endangered'; but one western population has shown us that despite all the other pressures, habitat restoration on a large scale can bring a population back from its descent into the 'extinction vortex'. Unfortunately, the severe 'drought' has also severely impacted this population that was previously in recovery.

Although the Queensland populations are also in diabolical trouble, this is where the majority of the evolutionary potential of the species resides – thus it is especially important to secure the future of Queensland's official faunal emblem. It is also a microcosm of the overall national situation: the ecology of the species is quite different in the south eastern corner, the western regions, the dry tropics and the wet tropics; so are the threatening processes, the precision of our knowledge and the amount of management attention.

Near extinction (Victoria) or complete extinction (South Australia) of southern koalas coupled with widespread translocation from genetically impoverished source populations has produced severe genetic homogenisation and loss of diversity. In Queensland by contrast, even the small and artificially established St Bees Island population off the central Queensland coast (small population and small island) has about twice the allelic diversity of the most diverse Victorian population and is more than three times as diverse as the much larger (population and island) Kangaroo Island population in South Australia. The Queensland island populations (both natural and introduced) also give the lie to the heresy derived from the southern experience that koalas cannot maintain stable populations on islands. The question though is not 'what's odd about Queensland koalas'? – they do just what one would predict for a large mammal with a low reproductive output. Rather the question is 'what's peculiar about southern koalas and/or southern habitats'?

The contemporary Queensland scene

The most comprehensive data that exist for any koala population are derived from studies of the high density south east Queensland populations. There is clear evidence that the coastal south east Queensland koala populations meet the International Union for Conservation of Nature (IUCN) criteria for listing as "critically endangered" and the Queensland *Nature Conservation Act 1992* criteria for listing as "endangered wildlife" – despite multiple nominations for such listing in the second half of 2010 no listing action has been undertaken by the Queensland authorities.

The south east Queensland populations are vital to the koala – the Macleay/McPherson Overlap Zone is the species' stronghold and probably has been for most of its evolutionary history, but perhaps two thirds to three quarters of Queensland's koalas inhabit the rest of the state! Our knowledge of the western and northern populations is less complete but nonetheless clearly demonstrates that there are serious problems – consolidating our knowledge of these inland populations and identifying major information deficiencies that need to be made good urgently, are the *raisons d'être* for this koala workshop in Rockhampton hosted by the Central Queensland Koala Research Centre.

Southern koalas

Proportionately the greatest historic koala habitat loss has occurred in Victoria and South Australia. Nonetheless the 'official view' in Victoria remains that 'over-abundance' is the dominant management problem, though this may be changing in response to recent catastrophic fires and emerging diseases (probably congenital)?

The southern koala now occurs over most of its pre-European occupation range, BUT its distribution is highly fragmented and much of the population is probably biologically unstable due to the near extinction bottleneck and the unintended consequences of large scale translocation of koalas.

The Senate koala inquiry

Having provided evidence at the Melbourne hearing of the Senate Committee, and made various additional submissions (along with other participants at this workshop) as well as having followed its deliberations and the unanimous report, I have to say the Senators 'got it right' - basically the committee has strongly urged Commonwealth Environment Minister Tony Burke to list the koala as threatened under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and has pointed out inconsistencies/inaccuracies in the Threatened Species Scientific Committee's (TSSC) previous advice to the Minister (ECRC 2011).

It is my strong belief that the TSSC will have taken the new and additional information provided to the Senate inquiry into consideration and come to the conclusion that whilst previously advising that the koala came close to but did not quite meet the criteria for EPBC Act listing, the evidence now is that it does pass the threshold for listing. Since the Senate committee assembled such a wealth of information to reach the obvious conclusion that the koala is in deep trouble and needs Commonwealth as well as state assistance and that the report was unanimously adopted (particularly since the committee membership represented all major Australian political parties – Australian Greens, Australian Labor Party, Liberal Party of Australia and National Party of Australia), I believe that the Federal Minister is most likely to determine that the koala should be listed as threatened for the purposes of the EPBC Act when he announces his decision. [*Note: Since the time of writing, this belief has subsequently been vindicated. Eds*]

Outcomes

In practical terms, without EPBC Act listing the Commonwealth will continue to do little but pay lip service to koala conservation. But if (as has transpired) the koala is listed, it seems clear that a number of issues will be prioritised and consequentially must be resourced. These issues will be considered by the participants in this workshop.

Population Estimations

The TSSC and the Senate report have identified the critical need for scientifically defensible and comparable population trend estimates from a much better representation of the species extensive range. This certainly does NOT mean that there should or could be a single methodology – a 'horses for courses' approach is required, BUT any methods must be verifiable and rigorous

'Data deficiency' cannot be overcome by fancier mathematical models – there is a desperate need for more and better representative reference sites (sentinel sites) and actual ecological surveys. Moreover, modellers must make use of actual data that are available, not ignore validly published data that don't match their preconceptions. Otherwise the 'rubbish in – rubbish out' aphorism is directly applicable!

There are robust methods for estimating koala abundance but all are resource intensive. For example, David Dique and co-workers searched 4695 ha using strip transects in the Koala Coast to observe 1792 koalas; as well as searching 64 km of line transects in the then Pine Rivers Shire to observe 82 koalas. "Indirect" methods (including faecal pellet surveys with rigorous calibration – such as devised by Ben Sullivan and co-workers) may be applicable for low density populations.

More generally, indirect methods (including detection of faecal pellets) can certainly be used to determine koala presence (though not absence unless stringent criteria are developed); as well as a role in ground-truthing of predictive mapping, establishing distribution patterns and for use in 'area of occupancy' assessments. Without extensive controls – which are heavily site dependent – that's about all they can validly achieve; as shown by William Ellis and co-workers, they definitely cannot be used to establish dietary preferences and generally can't be used to estimate abundance without extensive site specific calibration.

Unwise 'conventional wisdom'

Uninformed commentators and vested interests sometimes proclaim that there's no point reserving habitat (and preventing its development from making them "megabucks") – the koalas will all be killed by cars or dogs. They also take the pronouncements of some who focus on Koala disease issues to assert that in any case koalas are all doomed by disease, so habitat protection is pointless! This is a significant departure from reality – the amount of habitat available to koalas is the ULTIMATE determinant of how many koalas will survive in Australia; although preserving and restoring habitat is a necessary condition, it is not sufficient by itself.

Mortality from vehicles, domestic dogs and disease are the major PROXIMATE causes of mortality. High speed, high traffic volume roads must avoid koala habitat or be engineered (or retrofitted) to prevent koalas being killed or injured; dog ownership must be controlled to prevent attacks; current and emerging koala diseases must be managed.

But the most strategically important requirement is to prevent further net loss and fragmentation of koala habitat.

Doomed by disease?!?

The media has abounded with assertions such as: "Koalas are being infected with ………… and they'll be extinct in 10 years unless funding is provided to develop a vaccine." If 1984 insert "chlamydia"/if 1990 insert "retrovirus".

The real evidence indicates to me that koalas have co-evolved with both chlamydiae and koala retrovirus (KoRV) for at least a few million years and many (even biologists) do not appreciate that there is a significant difference between being infected and being sick. Peer reviewed evidence also shows that there are clear regional differences in the significance of disease impacts – through most of the species' current range disease is not a significant cause of mortality. In some places (e.g. south east Queensland), disease is certainly a significant issue and there are also concerns over the potential for welfare interventions to result in unintended facilitation of disease spread between various local populations.

Can these organisms lead to sickness and death in koalas? In the case of chlamydial disease, yes but NOT inevitably. In the case of KoRV probably yes in some circumstances, but its significance is unclear and certainly there is no evidence that it has the degree of impact of chlamydiosis.

Would a vaccine solve the problem? This seems like a reasonable idea for captive koalas, but even if a safe and effective vaccine could be developed in time (by no means assured given the experience of the lack of success with trachoma and genital chlamydiosis vaccine development for people, despite the expenditure of many million dollars by the World Health Organisation and American National Institutes for Health over several decades), there are major questions of logistics and even efficacy of use in wild koalas that have not been addressed by proponents. General deployment of a vaccine in wild populations is likely to lead to reduced resistance/tolerance and once undertaken would need to be continued forever – hardly a desirable management outcome!

To put disease into perspective, even though largely secondary to the other threats, infectious disease can be devastating; with most morbidity and mortality due to bacteria in the Family Chlamydiaceae, which affect eyes, urinary tract, reproductive tract and respiratory tract. These conditions are treatable with conventional therapies, which are particularly effective for eye disease. Infection often progresses to disease following habitat destruction (e.g. documented following Ney Road residential development and construction of Moreton Bay Road in the Koala Coast; inferred historically in Bega Valley). Almost all northern koalas are infected with KoRV, this is 'endogenised' (incorporated into the koala genome), so there's nothing that could be done about it even if there was unequivocal evidence that it was a significant problem.

Relocation to the rescue?!

The superficially seemingly reasonable but actually counter-productive approach of 'let's just move the koalas' when we want to flatten their habitat for some human enterprise is fatally flawed. The weight of currently published evidence shows that translocation as a response to development driven habitat destruction actually increases mortality and unless 'new' habitat is created, it's a 'zero sum game'. Translocation as a 'solution' to urban, mining, industrial or agricultural developments is contraindicated by population genetics in most circumstances – translocating coastal koalas to sites to the West of the coastal ranges or vice versa is especially unwise. Moreover recent experience shows that such translocations facilitate further habitat destruction and hasten local extinctions. Even in Victoria where translocation has been such a prominent feature of koala management in that state, the practice has now been stopped in response to accumulating evidence of the deleterious impacts of this activity.

This is not to say that properly conservation based translocations or genetic management may not have a place in supporting/restoring populations under pressure in appropriate circumstances; but only where there is compelling objective evidence that this will have positive outcomes for wild populations.

Conclusion

I am looking forward to hearing from the workshop participants about how the overall issues affecting Queensland koalas particularly manifest themselves outside south east Queensland – in other words "what's happening in the majority of the koala's Queensland range?"

Post-workshop note* (F. Carrick)*: Since the time of the workshop, koalas in Queensland, New South Wales and the Australian Capital Territory have been classified as vulnerable under the EPBC Act and added to the Australian threatened species list. Had Commonwealth listing not happened, it would have demonstrated the inadequacy of the EPBC Act to protect Australia's unique fauna until a species teeters on the very brink of extinction and provided the impetus to develop a national "Koala Conservation Act" that would protect this national and international iconic species. The Queensland Government (current and previous) by electing to 'play catch up' with the 'Feds', is in an incongruous position, since the key elements that led to Commonwealth listing are based on Queensland research. Far from being redundant and unnecessary "green tape" as reportedly characterised by Queensland's Premier Campbell Newman (ABC News 2012), the EPBC Act listing is vital: since under Queensland's *Nature Conservation Act 1992*, throughout most of Queensland (other than the south east corner) the koala presently has no more protection than brushtail possums, bush rats or eastern brown snakes (worthy fauna though they be, they certainly are not in the parlous situation of koalas).

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Theme 1. REGIONAL RESEARCH AND MONITORING OF KOALAS AND THEIR HABITAT

Regional research: perspectives from the field in central Queensland

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Koala research in regional Queensland is characterised by limited resources and considerable logistical difficulties. Despite a plethora of opportunities for research and what we think is the key requirement to study populations that are not under constant pressure from urbanisation, only a limited number of studies of basic biology in this area are supported through contemporary sources. Regional research is largely funded through independent resources such as companies, overseas partners and community groups. A large part of the support for regional research is through in-kind support from government agencies and local stakeholders. In particular Marine Parks Mackay have been the key supporter of the research into the ecology of koalas on the islands off Mackay.

The rationale for researching central Queensland's koalas is that these populations hold important information on koala conservation issues – such as the key limiting factors on distribution, where evolutionary potential lies, and even immune responses to disease. We can have long term field research 'laboratories' that (hopefully) won't be turned into a development site. We can pick from a whole suite of environments and have access to natural open systems and non-urban landscapes.

Despite working in remote locations on limited budgets, research in central Queensland, including inland sites such as Clermont and island sites such as St Bees Island, is at the forefront of delivering better understanding of a range of aspects of koala biology. There have been a number of empirical "firsts" from the regional research we've undertaken, including:

- The first comparison of infection and disease amongst koalas from within the urban environment with those in the non-urban environment (Ellis et al., 1993)
- The first proper examination of the relationship between koala behaviour and the spatial deposition of faecal pellets (Ellis et al., 1998)
- The first description of the relationship between koala tree use and actual koala diet – crucial work in our current understanding of koala biology and vital in protecting critical koala habitat (Ellis et al. 2002b)
- The first work to examine the physiological ramifications of climate change for the koala and for its distribution (Clifton et al., 2007, Ellis et al., 2010)
- The first genetic analysis of breeding success in free ranging koalas and the first description of their breeding behaviour based on molecular genetic information (Ellis et al., 2002a)
- The first examination of resource partitioning and a description of the spatiotemporal arrangement of free-living koalas (Ellis et al., 2009)

- The first description of sexual selection in koalas (Ellis and Bercovitch, 2011)
- The first ever study of the spatial and behavioural responses of koalas to koala bellowing, including the first description of the use of GPS collars and the use of remote listening stations to record koala bellows (Ellis et al., 2011)

Despite the comprehensive nature of the research and findings in regional Queensland, the take-up of knowledge into the larger scientific community seems slower than we would have hoped, and it is not uncommon to find results we have published being overlooked or omitted in other work. The result is that there is constant pressure for us to continue to work in this area to ensure that accurate assessments of habitat use and koala behaviour are incorporated in regional conservation plans. There are contemporary examples where we feel that failure to act on the best local knowledge could have a derogatory impact on koala conservation. Several current areas of concern are:

Immunology and disease

A review of recent literature suggests a “reinvention of the wheel” is underway with our understanding of chlamydial infections in koalas. In 1993 we published our finding that koalas that are exposed to chlamydial infection produce specific antibodies to this bacteria, and that non-exposed koalas will be seronegative (Girjes et al., 1993). In 2010 new research has emerged finding that koalas can produce antibodies to this disease, with no reference to the earlier research (Carey et al., 2010)

While koalas in central Queensland appear to live with chlamydial infection – which we would rather that they did not have to, they appear not to suffer as much as their south-eastern counterparts. But this situation is not widely known – with a current concern for the impact of disease leading one south east Queensland research team to pursue a chlamydial vaccine for the koala: a highly expensive and, on the basis of our data, an unnecessary work at least beyond south east Queensland. Concerns in southeast Queensland have led a push toward research into the disease, but it appears that some of the lessons of the past, as described above, are not being considered. We question whether the medicine for the south east corner is to be rolled out into the rest of the state, regardless of the information we have presented that shows that money could be better invested in other areas of conservation and management out here. It is clear that koalas in central Queensland harbour *Chlamydia*, but they do not necessarily suffer from it, so perhaps we should be looking more closely at this situation to gain a better understanding of what makes koalas resistant or tolerant to Chlamydia.

Indirect signs to predict occupancy

In the process of our work we take care not to assume anything about the koalas of central Queensland: for example they live in a range of environments, using different trees between locations and they eat a variety of trees. The open woodlands of central Queensland are fertile ground for conducting ecological research, and in the late 1990s and early 2000s we published findings revealing that koalas produce 150-175 faecal pellets per day (Ellis et al., 1998, Ellis et al., 1999, Sullivan et al., 2004). We used these data to assess population density and occupancy as well as to determine whether koalas used trees for eating or other purposes. However, in 2011 a paper was published which stated, on the basis of unpublished observations, that “koalas produce 80 faecal pellets per day” (Rhodes et al., 2011).

How might this impact our assessment of koala occupancy and distribution? If we incorrectly estimate key parameters that are used to inform models of koala distribution and occupancy, we may under or overestimate the occupancy by up to 100%. For a species on the brink of extinction that’s a disturbing outcome. For example, using the faecal standing crop method, several researchers combined to reveal a drastic decline in the number of koalas occurring in the mulga-lands of Queensland. This method relies on knowledge of the number of faecal pellets produced each day by a koala, so if we get this wrong by a factor of two, could we have the decline out by a similar factor? Fortunately that research group relied on the previously published data as a basis for their calculations. The consequences of not understanding the basic biology of the koala when modelling its occupancy, abundance or distribution are that one may overestimate or underestimate population size by a significant amount. This results in (1) errors on models informing government decision making; and (2) in the long run, suspicion that koala research is less precise than it could be.

Diet choice

Koalas use habitat in a complex manner – and much of what we know about how koalas use their landscape features has been generated in central Queensland. Information produced in this region shows that koalas use non-food trees as habitat. By analysing the composition of their faecal pellets we have generated complete pictures of their diet, so we can work out which tree species they sit in but don’t eat, and ask questions to find out what the purpose of these species might be – and how critical they could be to survival of koalas in general. Our picture seems different to that generated in Victoria though, where researchers rely for their model assumptions on statements such as:

> “Several studies have concluded that tree visitation is a reasonable measure of koala foraging.” (Moore and Foley, 2005).

It is of concern that while this may be the case in Victoria, there are no data to suggest this, and all our data from central Queensland seems to contradict it. What are the implications of such assertions for the assessment of koala habitat? How would this affect planning for koala habitat requirements in Queensland (and has it)? We need to ensure a high level of intellectual rigour when dealing with a species that is in decline. Reliance on the location of palatable tree species to determine habitat quality is a key concern for central Queensland koala conservation. We now know that koalas require non-food species in their habitat in order to survive. Sometimes they require a high proportion of these often-shady species in hot dry and hot wet environments. If planners retain only the habitat dominated by tree species that are thought to be palatable, the koalas may be doomed.

Key questions

Our research priorities for the assessment of preferred koala habitat were focussed on actually determining what koalas were and were not eating, to assist us designing rehabilitated landscapes for koalas. Clearly, a “day use = diet” model would result in a lopsided landscape in central Queensland, weighted toward many inedible species. These non-food species seem to be important to koalas though, so we set out to find out why. By placing temperature loggers in the canopy of trees koalas used during the day and night, we were able to identify which trees provided greater protection from the heat of the day and this helped to explain why koalas would leave their food trees to rest in these trees during the day.

Figure 1 shows ambient day temperature plotted against the in-canopy temperature in two species of trees that koalas utilise at Blair Athol, central Queensland. Although poplar box is a favoured food species, its in-canopy temperature tracks the ambient temperature closely compared to other species, while the tea trees are not a fodder species, but are much cooler than poplar box. Both of these trees are important to koalas, but koalas will be regularly found in tea trees even though it is not represented in their diet.

Conclusions

With limited funds, a fluid body of supporters and working in a difficult environment, in central Queensland we are producing quality research outcomes with direct benefits to understanding koala ecology. These advances are very slowly taken up. We need to ensure that the research from this area is built on, and not allowed to wither. Increased resources need to be directed to these areas and these projects – the answers to many of the problems of koala conservation are waiting here.

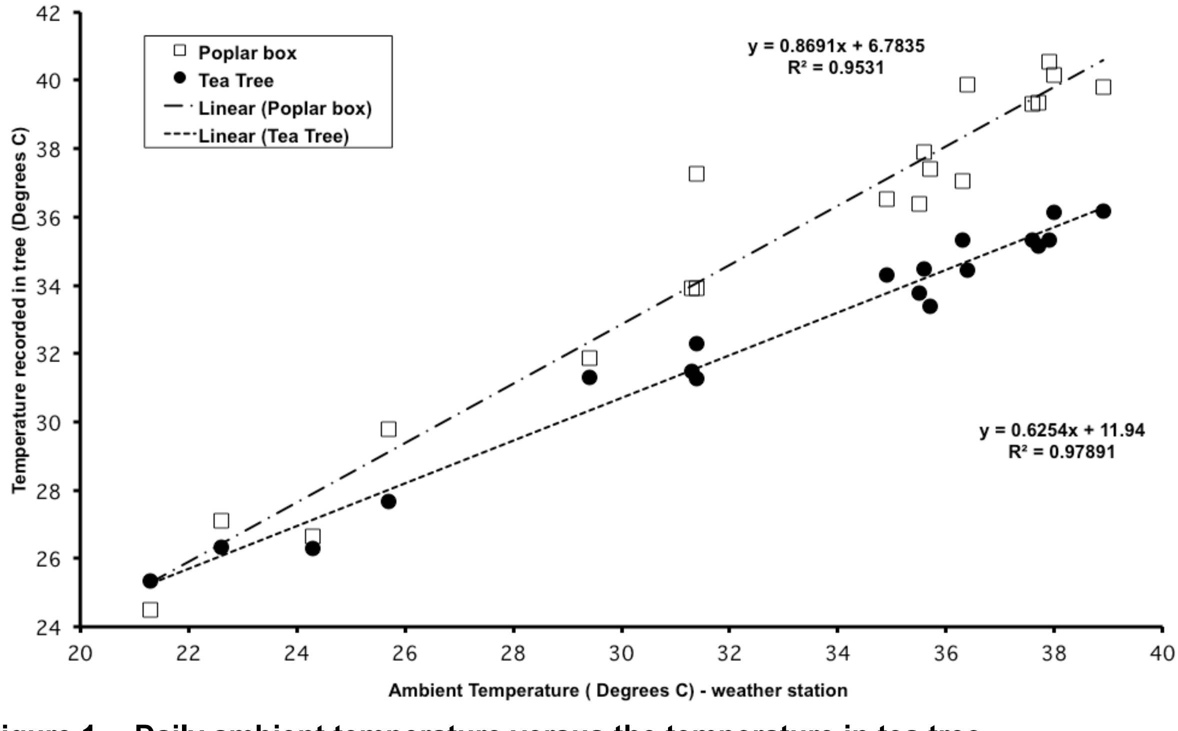

Figure 1 Daily ambient temperature versus the temperature in tea tree (*Melaleuca linarifolia*) and poplar box (*Eucalyptus populnea*) at Blair Athol, Queensland.

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The Koala Venture Research Partnership: an overview of 24 years of regional koala research in central Queensland

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The Koala Venture research partnership between The University of Queensland (UQ) and Rio Tinto Coal Australia (RTCA) was established in 1988 at the invitation of RTCA. It has given us an opportunity to collect a rare and highly valuable long-term data set that includes parameters that are difficult to get a handle on, such as how many young an animal produces during its life, and how long an animal lives. RTCA has sponsored this research through that entire time (24 years to date). They've shown great commitment to furthering the understanding of koalas on their mine sites and more generally, to improving our understanding of the ecology of inland koalas.

The project commenced in 1988 in response to mine employee concerns about the number of koalas seen at Blair Athol Coal Mine. They spoke to management who then contacted UQ to ascertain our interest in commencing a koala research project. The community in the area (Clermont township and surrounds) is generally well-aware and supportive of the Koala Venture project. Research is now conducted at two mine sites. It began at Blair Athol Coal Mine in 1988, which is now approaching closure [*Closed in late 2012. Eds*], and was expanded to include the recently established Clermont Coal Mine in 2006. The Clermont project allowed the research team to see changes in the koala population during the development of the mine (which was missed at Blair Athol). At Clermont Coal Mine, land clearing is still happening while at Blair Athol the mine is now rehabilitating areas they've finished mining.

The two mines are separated by about 6 km (Figure 1). Habitat is quite continuous between the two mines and includes Apsley State Forest, so there is potential for koalas to move between both mine sites.

The aim of the Koala Venture partnership is to enhance koala management and conservation through improved scientific understanding. Data is collected on koala movement, density, home range size, habitat preferences, breeding, growth, longevity, dietary preferences, disease types and expression, response to vegetation clearance, and use of rehabilitated areas. This is the longest-running ecological study of a wild koala population, as it has continued now for 24 years, bringing many enormous benefits that can only be obtained through long term research. It is also important in terms of community support – a school outreach program involves students coming along for a catch or tracking period. This helps build community support for the partnership and improve awareness of koalas, when the kids tell their dad or mum about the program. It is a flagship project for Rio Tinto and there have been numerous good news stories to come from the partnership.

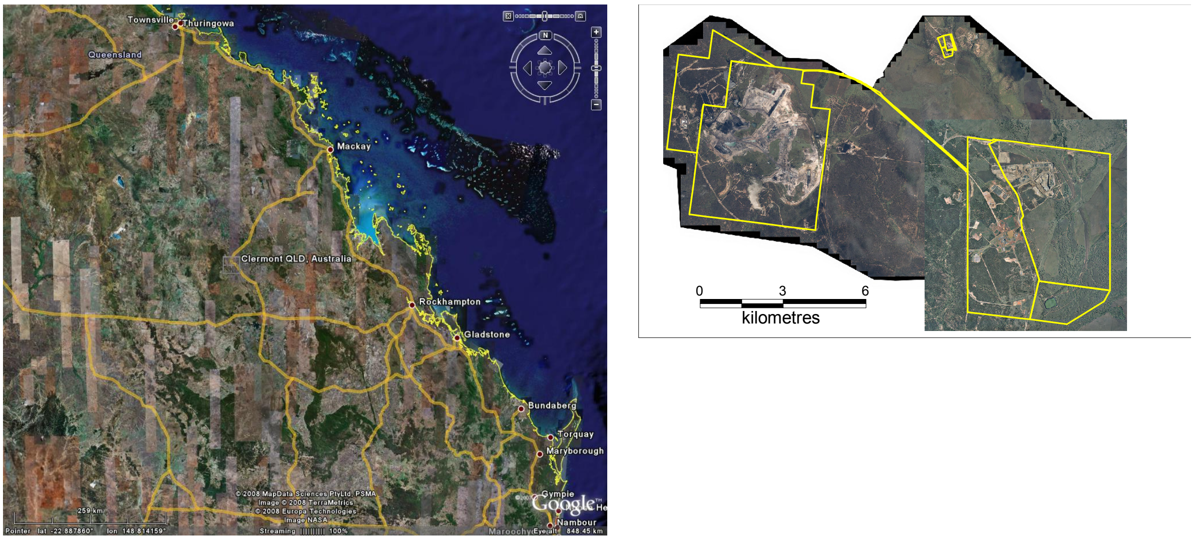

Figure 1 Location of Blair Athol Mine and Clermont Coal Mine.

The two field sites have different influences. Blair Athol Mine is characterised by poplar box (*Eucalyptus populnea*) and ironbark (*E. crebra*) forests, whereas Clermont Mine is mostly covered by coolibah (*E. coolabah*) woodland. Clermont has richer, darker soils, ephemeral streams/creeklines that are lined by black tea tree (*Melaleuca bracteata*), which are important shade trees for koalas during warmer periods. Blair Athol has fragmented remnants and rehabilitated areas, but spot clearing is still occurring, while in Clermont there are not yet any rehabilitated areas, and clearing is currently occurring over a broad area, eating into an extensive tract of woodland.

The general research approach is to visit the mine sites three to four times a year for 7 to10 days at a time, and to catch and collar as many koalas as possible in the areas of interest. Basic health checks are done on captured koalas, body measurements and DNA samples are taken, and ear tags implanted. Many of the captured koalas are also fitted with collars that permit them to be radio-tracked. In recent years we have moved from using VHF collars to GPS data-logging collars, which has revolutionised what we can learn about collared koalas. GPS collars are less disturbing to the koalas because we don't need to be there to track them as frequently, and we can program the collars to log positions at set intervals.

Many of the findings of the Koala Venture partnership have been published by William Ellis and Frank Carrick over the years, but it really is a big body of work. We would know a lot less about koalas in general without this long-running program. Home ranges of koalas studied during the program are massive compared to those in South East Queensland (60-130+ hectares versus 1-10 ha, respectively). Dietary preferences vary greatly between sites – at Clermont Coal Mine the koalas eat 95% *Eucalyptus coolabah*, while at Blair Athol Mine the koalas have a preference for *E. populnea* (59%) and *E. crebra* (10%).

We've tagged utilised trees to look at reuse of trees by koalas. From that we found that 65% of utilised trees were only used once and were not reused by another koala. We've also observed that diet and shelter/roost trees vary and are not always the same species. For example, *E. melanophloia* comprise just 2% of the diet, but are used for daytime sheltering 8% of the time. On Clermont Coal Mine the black tea trees are used more frequently in the summer months and their use is probably driven by thermoregulatory demands, as their microenvironments are considerably cooler.

William Ellis has published on the genetics of koalas at Blair Athol Mine and surrounds. Based on samples from all males caught in the population the “Travelling Salesman” hypothesis of roaming males was established, because approximately 50% of the sampled offspring couldn’t be accounted for/assigned to the resident males using paternity analyses. Our GPS collars have also shown that some males stay in the monitoring areas for only short periods of time. This sort of information is very important for understanding genetic exchange and disease transmission. We know that chlamydial infection is widespread in the populations but that there appears to be very low levels of overt disease expression.

We’ve seen strong seasonality in reproduction, with 60% of births occurring over summer and early autumn, but we’ve also seen that koalas can breed at almost any time of year on these sites, as in other parts of the state. There was a massive reduction in reproduction during drought years but a quick recovery in the few years after the drought ended, and now five of the six female koalas fitted with radio collars are carrying young (as of October 2011).

At Blair Athol Mine rehabilitated sites as young as 12 years are already being utilised by koalas. However, not a lot of sites have been rehabilitated to suitable koala habitat at this stage, so most of the rehabilitated areas are not enticing koalas to recolonise. But in those areas that have been recolonised, trees as small as 8 m high are being utilised by koalas for feeding and sheltering.

Clearing strategies at the new Clermont Coal Mine are crucial. The first acute, broad-scale clearing that was undertaken in 2008 had some unfortunate consequences for the collared koalas with several dying as a consequence of rapid landscape change. A new clearing strategy has been developed and proposed to the mine; it involves reducing resource availability ahead of clearing by ring-barking trees well in advance so that koalas will move out of their own volition prior to any bull-dozing.

Over the past five years koala movement has been studied using GPS collars. To illustrate the enormous benefit of these collars let’s consider a male koala named *Bullseye* that was caught on Blair Athol Coal Mine. *Bullseye* was fitted with a GPS data-logging collar and roamed far and wide over the following months, during which time we obtained several thousand GPS fixes. These revealed *Bullseye* had a relatively long, linear, home range (several kilometres) comprising several areas of intense activity and other areas of infrequent use. We now have this kind of information for lots of animals, and it’s extremely useful for investigating home range size, shape and overlaps, habitat use and preferences. It also highlights the mobility of koalas and the potential for koalas to move between the two mine sites.

One of the main ongoing threats to koalas on the mine sites and in regional Queensland is habitat loss, especially broad-scale clearing that is generally done over short timeframes. Broad-scale clearing still occurs on many developing mine sites in regional Queensland. Sadly, many mine sites aren’t rehabilitating adequately and they aren’t being held to account by regulators. A lot of land is appropriate for restoring to koala habitat in central Queensland but it seems the opportunity is largely being missed. We’ve also found that more disease expression occurs during stressful periods (such as land clearing), and vehicles (mine traffic and road traffic) are major threats. We've lost tagged animals to vehicle strikes and have also seen numerous koalas killed on the highways in central Queensland. Unfortunately the frequency of these strikes is likely to increase as mine-related traffic increases in the region. Wild dogs also present a problem in the region. Packs of wild dogs attack koalas and we have lost koalas in this way, including immediately after clearing when koalas presumably spend more time on the ground, disoriented and searching for trees that are no longer there. And it remains to be seen how forecast climate changes will impact koalas at these study sites but evidence suggests that an increase in the number of extreme heat days and reduced annual rainfall will take further toll on inland koalas.

There is a paucity of knowledge on Queensland's inland koala populations. Current research on managing koalas during clearing is important as very little has been written on this activity, which must have caused the direct death of countless thousands of koalas during the development of agriculture in Queensland. Is koala-sensitive clearing actually possible? We also need more information on the drivers for koalas recolonising appropriately restored habitat. We don't yet know enough about koala abundance and distribution throughout central Queensland. We are regularly asked to generalise from our two study sites but even those two relatively closely-linked sites are so different that it's difficult to extrapolate to the rest of the region with adequate certainty.

The major difficulties with effectively surveying koala distribution and abundance are limiting our conservation and management efforts in regional Queensland. In remote areas we're looking at solar-powered acoustic sensor stations that remotely record koala bellows (and hence indicate presence and possibly some indication of abundance) but we need more data on details such as how far away you can detect bellows and how to convert to a density estimate. We're also trialling unmanned aerial vehicles (UAVs) with thermal-imaging cameras to try and survey koalas from the air.

The keys to sustaining koalas in central Queensland are greater efforts to understand distribution and abundance, improved habitat protection and restoration (even sites that are currently protected aren't safe from the expanding resource industries), greater accountability and regulation (there are 97 coal projects interacting with koala habitats in central Queensland – only one project has a dedicated program dealing with koala issues and only one site has demonstrated effective koala habitat restoration). Further research across the koala's regional range is required and this will need adequate funding.

Acknowledgements: Fellow UQ staff, RTCA staff, the people of Clermont, the koalas of the region, photographers.

Overview of Koala Research Centre study sites

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Introduction

This paper provides a high level overview of the extent of the research that the Koala Research Centre of Central Queensland (KRC) undertakes.

Priority research targets for the KRC include:

1) understanding nature, extent and regional variation in koala habitat (critically including anthropogenic habitat);
2) understanding current koala distribution and relative abundance;
3) describing and delineating regional genotypic and phenotypic variants;
4) describing regional habitat utilisation strategies;
5) identifying key environmental drivers in population dynamics and habitat processes; and
6) monitoring trends in koala abundance and health as well as habitat health.

Currently there is a poor understanding of trends in abundance and health in koala populations and in the plant communities upon which they depend. Indeed there is no clear awareness of what constitutes a healthy koala population or a healthy koala habitat.

The sites

The current KRC research sites extend from Tambo in the south west to Hughenden in the central north west, to Springsure, Clermont, Collinsville, Mackay's offshore islands, and the St Lawrence coastal plain. All KRC research is undertaken in collaboration with the community and allied institutions. The sites are classified based on the types of habitat the koalas are using (Figure 1) including the tropical acacia woodlands near Hughenden, riparian systems in Mitchell Grass Downs and wet and dry tropical and sub-tropical woodlands closer to the coast.

Land holder knowledge is critical providing a wealth of local site knowledge. The property owners and their families give advice on where koalas are found while diary notes provide insight into seasonality and frequency of sightings. Some habitats are difficult to study. There are logistical challenges given the relative remoteness of the sites and the low koala population density. At times the researcher may find only one koala after two days drive. With the help of land owners the researcher can progressively build the knowledge base in the different koala habitats. A summary of the current knowledge base across these sites is provided in Table 1.

Table 1 Summary of current knowledge and gaps and major supporters at each of the major KRC study sites.

(**CQKV– Central Queensland Koala Volunteers, QPWS – Queensland Parks and Wildlife Service (marine and terrestrial), AKF – Australian Koala Foundation, CHRC – Central Highlands Regional Council, NRHS – North Rockhampton State High School, UQ – The University of Queensland**)

Habitat	**Tropical Acacia Woodland**	**Dry Tropical Woodland**	**Humid Tropical Forest**	**Humid Tropical Woodland**	**Mitchell Grass Downs**	**Dry Sub-Tropical Woodland**
Location	Hughenden	Collinsville	Mackay offshore islands	St Lawrence	Moorrinya NP and Tambo	Springsure and Biloela
Landholder knowledge	X	X	X	X	X	X
Tree use	X	_	X	X	X	X
Diet	X	X	X	_	X	X
Floristics	X	_	X	_	X	X
Environmental variables	X	_	X	_	X	X
Genetics	_	_	X	_	_	X
Behaviour and habitat use	_	_	X	_	_	X
Conservation biology and management	_	_	X	_	_	X
Support and collaboration	CQKV, R and B Rogers	CQKV, QPWS	CQKV, Koala Ecology Study Group and Koala Study Program, UQ, QPWS, Earthwatch	CQKV, DTMR	CQKV, QPWS, J and J Skelton	AKF, BHP Foundation, Xstrata Coal, NRHS, CHRC (Springsure), CQES, Koala Study Program, UQ, QPWS, Earthwatch

The KRC has been working on the offshore islands for over ten years and data collection is ongoing. The site is well established and the KRC is looking to better integrate study programs to develop a true integrated long term monitoring site.

The Mitchell Grass Downs sites are some of the most interesting koala habitats in central Queensland. The habitat is a narrow strip of riparian woodland set in large expanses of rolling grasslands. The sites also illustrate some of the interesting contrasts in understanding koala ecology in regional Queensland. In Clermont koalas in are quite abundant in the coolabah (*Eucalyptus coolabah*) forest and their diet consists of 95% coolabah (data from Sean FitzGibbon and Frank Carrick, unpublished). However in the Mitchell Grass Downs there are virtually no koalas in the coolabah forest – koalas can be found in the river red gum (*E. camaldulensis*) forest. Each habitat has unique characteristics and koala responses are going to be somewhat different at every site.

There is also a long history of research in the dry sub-tropical woodlands of Springsure and Biloela. Koalas have been reasonably well studied in this area since the 1970's, however there are big challenges in understanding and responding to the recent regional collapses in koala populations.

Research Focus

Currently KRC research is broadly focused on understanding the range of habitats in the region, strategies koalas use in those habitats, environmental factors impinging on those habitats and the strategies employed by koalas to accommodate these factors, the species' resilience across the landscape and over time, and long term changes to habitats and populations.

Forest habitats are dynamic systems. There are regular changes through succession in plant communities, and these are influenced by whichever environmental factors are dominant at the time. Habitats change in relation to the management – deliberate or otherwise – that humans impose on it. Understanding koala habitat is as critical as understanding the animals themselves.

In some areas, the "remnant vegetation" mixture of ironbark (*E. crebra, E. melanophloia*) and Mt Coolabah (*E. orgadophilla*) woodlands is mostly regrowth from 1920s and 1930s when the land was extensively cleared for sheep and dairying. What we now see as koala habitat was historically something else.

Increasingly koala habitats are being fragmented across the state.

There is a critical shortage of financial and logistical resources in central Queensland to undertake research in remote areas and the significant habitats that have not yet been studied. For example, frequently koalas can be found in the harshest, scrubby *Acacia* communities, instead of the relatively fertile, well watered Queensland blue gum (*E. tereticornis*) habitats fringing streams. The KRC considers some of these difficult habitats will provide the refuge for the koala in central Queensland in the future. Adequately protecting and managing these obscure habitats requires research and that, in turn, requires resourcing.

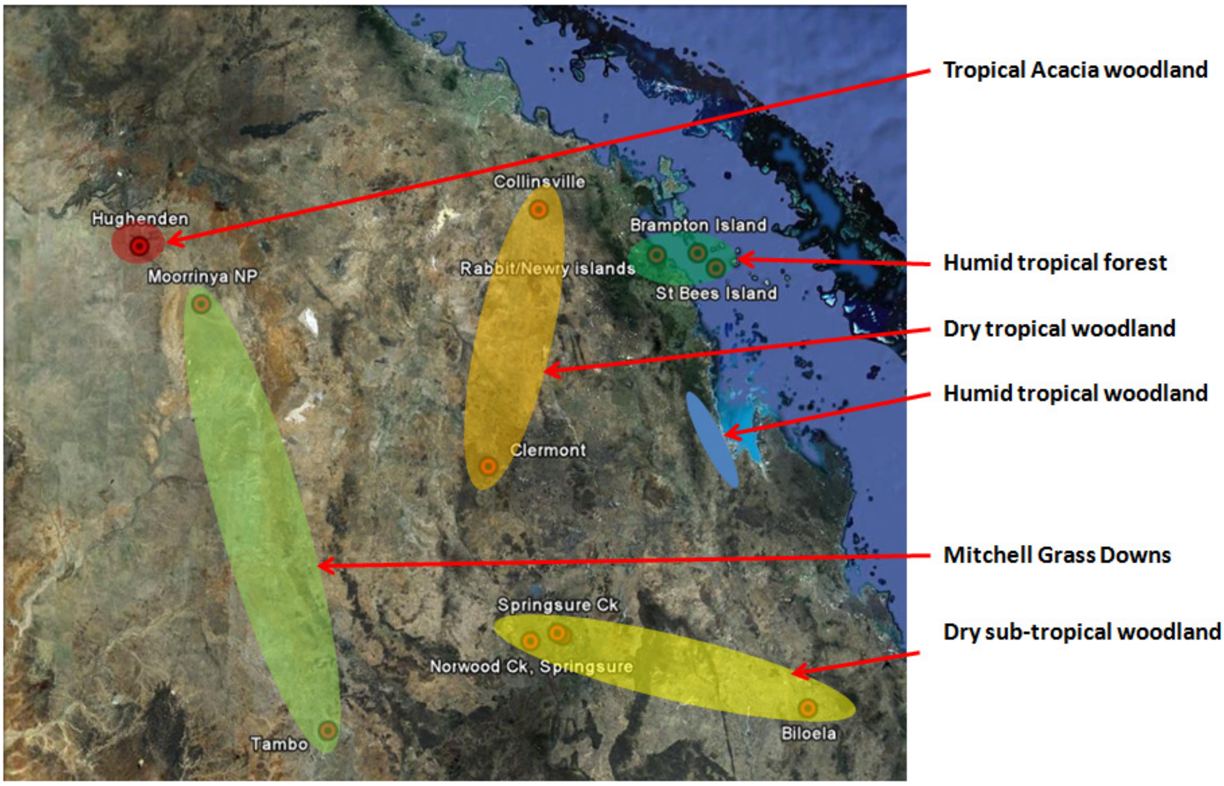

Figure 1 Koala research sites and habitat types in central Queensland.

WORKSHOP SESSION 1: Effective monitoring of koalas and habitat in central Queensland

In this session we discussed the issues and considered solutions to designing appropriate monitoring protocols for koalas and their habitat in central Queensland.

Issues:

- The first issue that arose was that of scale – the area is vast, containing a range of land uses and koala population densities.
- Variability, both in terms of the landscape characteristics and the challenges facing monitoring programs would need to be overcome.
- Correlated with the scale is the cost of any monitoring program.
- Whether a uniform method was appropriate was also discussed: some suggest a single national method should apply, but does one style suit all sites – even within the central Queensland context?
- Koalas in areas of central Queensland occur at very low densities, so some methods would be inappropriate or cost/time prohibitive to undertake. The detection of trends would hence be very difficult.
- Problems associated with selecting sites that would be representative were discussed: both temporal and spatial variability would need to be addressed and the changing nature of land uses across the area could force changes and an adaptive approach would be required. Site security was a big issue: resource extraction was changing the nature of site security.
- A range of factors from cryptic nature of koalas to remoteness of sites would need to be factored into any design of monitoring programs.

Ideas/solutions:

- A number of ideas were put forward on this topic and the pros and cons discussed among experts using or trialling the technologies and familiar with the techniques.
- Depending on landscape characteristics there is the opportunity to utilize aerial platforms for thermal imaging. This is something that could be resourced through industry partnerships. The capability for extensive search areas to be covered with small teams utilizing new technology should be examined.
- The use of novel techniques such as trained dogs is being trialled in other areas and this could form part of a larger program.
- The use of landholder surveys to acquire dependable presence (but not absence) data was recommended as appropriate to the scale and land tenure characteristics of central Queensland. Similarly semi or fully automated survey systems such as the sound monitors in use at some sites could provide evidence of presence remotely.
- There is a need to establish sites that would become sentinel sites – key areas with quality datasets preferably in significant koala habitat and resourced as part of long term research sites to monitor trends.
- Data collection should be targeted to inform models, however, the data collection does not need to conform to a standardized model as long as the data are transferable or comparable between sites. Different approaches can be applied depending on specific questions e.g. quick assessments as compared to comprehensive assessments to yield different but essentially/equally useful data in the context of the question.
- There needs to be an approach that monitors habitat as well as the koalas within the landscape.

Two tasks were identified for action as a result of this workshop:

1) Identify the best methodology/ies for monitoring koalas and habitat in the region – some testing is underway and reports/communication regarding the success or otherwise of the technologies needs to occur to expedite the roll out of effective techniques.
2) Initiate a small group to discuss this further.

Theme 2. CENTRAL QUEENSLAND'S KOALA ISLANDS

Managing Central Queensland's Koala Islands

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Introduction

Queensland's koala islands extend from Stradbroke Island near Brisbane in the south to Magnetic Island near Townsville. Off the coast from Mackay are the central Queensland koala islands of St Bees Island and Brampton Island (to which koalas were introduced), as well as Rabbit Island and Newry Island (which house native koala populations). There are also accounts of recently extinct koala populations on Great Keppel Island, Aboriginal accounts of koalas on Fraser Island before Europeans arrived, and reports of koalas on Quoin Island in Gladstone harbour although these were most likely introduced.

Importance

The central Queensland koala islands are important. Rabbit Island is one of only two (including Stradbroke Island) surviving native island populations and, as such, are relics of pre-European distribution. The island habitats provide refuge against mainland impacts, disease outbreaks and potentially against some climate variability or uncertainty.

A wild laboratory

From a research perspective the island habitat and koala populations provide an excellent natural laboratory. The koalas show little aversion to humans and are frequently encountered low in the tree canopy – allowing close observation by those studying animal behaviour. Also the tree canopies are relatively low facilitating the study of the plant community forming the koala's habitat.

There is little disturbance – given the island environment and limited development. National park declaration over the islands provides security against future development and secure tenure for long term research.

However, one of the challenges in managing these national parks is maintaining the natural values of the island and the koalas at the same time. There are inherent conflicts and planning is complex. This is particularly challenging because each island population has different degrees of vulnerability and habitat resilience.

Risks

There are limited fodder species on St Bees Island – 90% of the diet is derived from one eucalypt species (Queensland blue gum *E. tereticornis*). In contrast, Brampton, Rabbit and Newby Islands all support range of fodder species. On St Bees Island the koala population is vulnerable to eucalypt defoliation by fire, drought, insect attack and foliar diseases (e.g. myrtle rust).

Insect defoliation

All forests experience insect attack at some times – commonly outbreaks affect one species within a forest degrading leaf quality or defoliating the tree. Seasonal declines in Queensland blue gum leaf quality due to insect attack has been reported from St Bees Island. A severe infestation would threaten the fodder supply for the koalas on that island.

Drought

Researchers have observed the loss of a range of tree species, both koala fodder species and non-fodder species, on St Bees Island during drought in the early 2000s. If climate change predictions eventuate a general drying out of the island landscape together with a shift from forest habitats to woodland is predicted.

Fire

Most critical for the islands is the effect of fire – natural fires on these islands are rare – the majority of fires are caused by escaped recreational fires or managed fires as part of national parks management regimes for the islands. Because the wooded communities are low forests the koalas may be a few metres from the ground. Consequently there is a risk of scorching the koalas and the forest canopy, the latter resulting in leaf drop and the loss of fodder resources for the surviving koalas. There is a dominance of tall tropical grasses – exotic and native – on Rabbit Island, meaning there's a lot of fuel available to carry the fire into the forest canopy. There's been a reported dramatic decline of koalas on that island following a national parks fire in the 1990s. Also, lantana (*Lantana camara*) is present on all the islands and on St Bees Island lantana is expanding, adding to dry season fire risk. Finally as visitations to the island increase there is also an increased risk of ignition events.

Risk and resilience

When you look at the vulnerability of the koala populations on these islands (Table 1):

1) St Bees Island has the highest koala population and also the highest public profile as "the" koala island. However, because of the koala's reliance on a single fodder species the population can be considered to have little long term resilience. There's a high risk to the koala's food source from drought as Queensland blue gum has a very low capacity to manage moisture stress. St Bees Island has a medium fire risk as although there is not as much tall grass as on Rabbit Island there is increasing density of lantana and there is an active burn program from Queensland Parks and Wildlife Service. There is a high risk to fodder resources from insect attack and foliar disease because the koalas are reliant on a single fodder species.

2) Brampton Island has a low fire risk as the dominant forest community is moist and unlikely to support an intense fire – under current climatic regimes! The island has a range of *Eucalyptus* and *Melaleuca* species that koalas can consume resulting in a low risk from insect attack and foliar disease threatening fodder resources.

3) Rabbit Island has very high seasonal grass loads so fire is a very high risk to koalas and fodder resources. Newry Island is intermediate in vulnerability as the tall exotic grasses are more restricted in distribution. Koalas swim the narrow channel between Newry and Rabbit Islands, so the two islands support one population. Also fodder

resources are relatively secure as there is a range of *Eucalyptus* and *Melaleuca* species that koalas will eat on both islands.

Table 1 Potential impacts on fodder species and vulnerability of koala populations on each island.

Island	Drought	Fire	Insect Attack	Foliar Disease
St Bees Island	high	medium	high	high
Brampton Island	low	low	low	low
Rabbit Island	low	high	low	low
Newry Island	medium	medium	low	low

Plant community dynamics

Another issue for the koala islands is that the structure of koala habitat changes over time. This change happens under influence of climate changes, pests, management decisions and natural successional processes through time. The drivers of change act in concert. This change can be most clearly seen on Brampton Island (Figure 1) where there has been a rapid and extensive shift in the extent of woody communities on the island at the expense of grassland and a change in composition from open woodland to closed forest with a general loss of open grassy understorey being replaced with closed shrubby understorey. These changes correspond with the removal of grazing by goats in 1969 and the imposition of a management regime that excluded fire where possible. In concert with a succession of good rains in the 1970s these changes have caused a shift from open grasslands and grassy woodlands through to open shrubland and you now see fire sensitive rainforest plants living in eucalypt communities where they don't usually grow because of fires.

A similar process has occurred on Rabbit and Newry islands.

On St Bees Island, in the absence of fire and under moderate grazing pressure from goats a gradual thickening of the woody communities has been evident from the 1970s. However, with the virtual eradication of goats over the last five years there has been a rapid acceleration in the rate of woody growth and grassy woodlands have been largely lost. These structural changes are occurring at the expense of long term persistence of koala habitat.

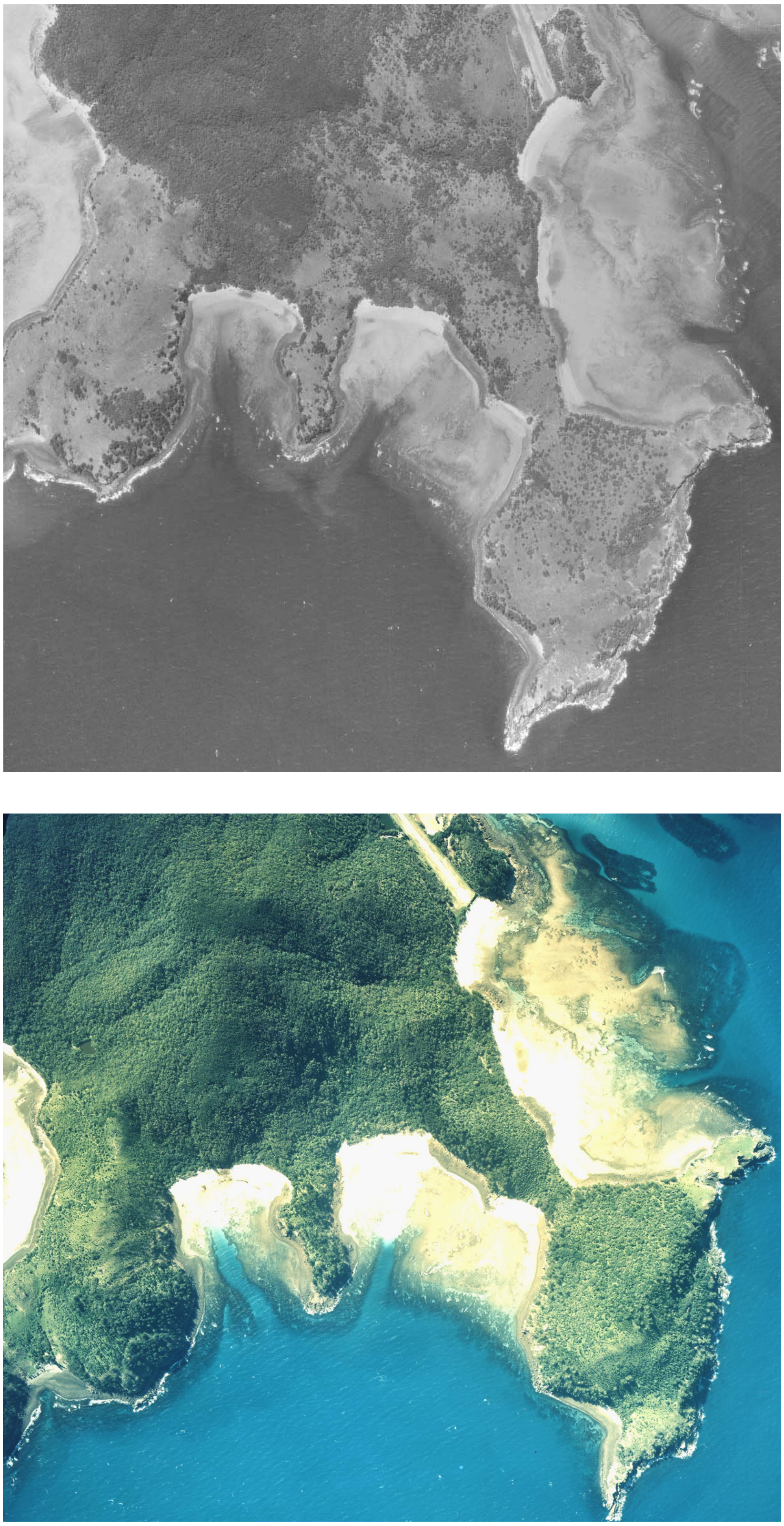

Figure 1 Changes in gross vegetation cover on Brampton Island from 1975 (above) and 2003 (below).

Is killing goats and burning bush the answer?

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Introduction and background

This presentation examines a project whose aims include promoting koala conservation on a national park island – St Bees. It will explore the management and ecological context for the project. We'll focus on the natural and scientific values of the island, impacts on those values, what we want to achieve in relation to those values, the means to do so, and progress so far.

All national parks have significant values, a range of threats, and often management requirements that conflict or at least require considerable planning and on-ground effort to make them gel. While not all of the presentation is directly relevant to the koala it provides the context of management for koala conservation on St Bees Island, especially as koalas range across the whole island and use, or traverse, all ecosystems.

St Bees Island is part of the South Cumberland Islands National Park Aggregation. It is 20 km north east of Mackay, and about 1000 ha in area. It is a continental, volcanic island, and its highest peak is about 370 m. St Bees Island has scientific, cultural, aesthetic and natural values. There are 14 regional ecosystems on the island (across four land zones) including six 'Of Concern' and three 'Endangered'. It is nationally and internationally recognised as an important natural laboratory providing answers to research questions and guidance for management options for island populations elsewhere, including 'islands' on the mainland.

Despite its significant values, it is by no means an untouched wilderness and is not without its problems.

Goats were introduced to St Bees Island in 1905. Periodic culling by lessees occurred between 1968 and 2001. The island was a grazing property between 1907 and 1970 and was heavily grazed by sheep, cattle and horses. Swamp wallabies, pretty face wallabies and koalas were introduced for the pleasure of landholders and visitors. Koalas were introduced from the Proserpine area in 1938.

The island was gazetted as a national park in 2001. The koala population was a significant factor in finally achieving national park status for the island because of the nationally, and now also internationally, recognised scientific value of this island population and the research underway.

In 2005 Queensland Parks and Wildlife Service launched a 'conversation' to examine the values on the island, what the values should be managed for, and therefore what actions, performance indicators and evaluation should be put in place. This conversation was triggered and informed by: the results emerging from the work of the koala researchers; historic accounts of changes on the island – particularly with grazing; and recent changes in the landscape that were of concern. Some examples follow.

Queensland blue gum (*Eucalyptus tereticornis*) – the only year-round koala fodder species on the island – was not regenerating whereas bloodwoods (*Corymbia* spp.) were regenerating. There were neither blue gum seedlings nor saplings – indicating that regeneration had been poor to non-existent for some time. Blue gum seedlings are extremely palatable to grazers so it seemed likely that selective grazing by goats and possibly swamp wallabies was having a significant impact on woodland demographics. Furthermore, a lot of the eucalypt woodlands were being encroached by rainforest and were no longer able to be burned to help maintain their structure and composition.

High sheep stocking rates in the 1940s were documented as having triggered substantial change in grassland and shrubland communities (Berck 1995).

In the early 2000s grasslands that were dominated by white spear grasses (*Aristida* spp.) – grasses that are themselves indicative of long-term overgrazing – declined into an even more degraded state quite suddenly. The decline was probably due to drought plus ongoing heavy grazing by goats and an absence of fire. From almost 100% cover of white spear grass some areas became low lantana (*Lantana camara*) shrublands while others were dominated by Jamaica snake weed (*Stachytarpheta jamaicensis*). The remnants of blady grass (*Imperata cylindrica)* also virtually disappeared. Impacts from goats also included ringbarking of trees and removal of ground cover, including leaf litter, thereby creating patches of bare ground prone to erosion. Amongst all the negative impacts from goats there was one positive – the widespread lantana was being kept in check by heavy pruning.

The project

It was clear that a range of positive and negative interactions and feedback loops characterised the relationships between the landscape, goats, fire and recruitment. The island's history of intensive land use, long-term grazing by domestic and feral animals, long absence of fire and ongoing heavy grazing by goats appeared to be contributing to significant vegetation change in terms of community structure, composition and distribution. A range of potential options, conservation outcomes and management actions were explored and in 2006 a project was approved with the following objectives and desired outcomes.

Objectives:

- maintain, and in some cases restore, the distribution, structure and composition of the vegetation communities; and
- maintain the koala population and its habitat – in particular the Queensland blue gum woodlands.

Desired outcomes:

- natural ecological processes are restored;
- a range of vegetation communities are maintained including grasslands, grassy to shrubby woodlands and rainforests that, by 2020, are substantially free of lantana and provide suitable habitat for a sustainable koala population into the future;
- successful recruitment of Queensland blue gum in the eucalypt woodlands;
- grasslands have substantial ground cover, diverse species composition and low abundance of weeds and white spear grass; and
- a healthy and sustainable koala population persists on the island.

It was recognised that several actions would be needed to achieve these objectives, including goat control, lantana control and the implementation of planned burning. Employing one of these actions alone was unlikely to be effective. For example, controlling goats without controlling lantana would be likely to lead to lantana thickets across the island, thereby impeding recruitment of eucalypts and the movement of animals. Performance criteria, against which to monitor progress towards our objectives and desired outcomes, were established.

Monitoring plots were established in October 2006, goat culling commenced in October 2007, and some lantana spraying began in 2007. A detailed vegetation survey, map and assessment of vegetation change since 1960 (oldest aerial photography available) was completed in 2009 (Kemp 2009), and planned burns were undertaken in 2009 (small trial) and 2011 (largely in grassland).

The monitoring program involves a primary site in each of three vegetation types: rainforest, Queensland blue gum woodland and lantana shrubland (previously grassland). Each monitoring site includes two plots, one that is fenced to exclude goats and one that is open to grazing. Three additional photo monitoring plots have been established in grasslands. The sites were established in 2006 and since then have been monitored annually up to and including 2010. Monitoring will resume in 2012.

The vegetation parameters being monitored at each site are:

- foliage projective cover – overstorey;
- leaf area index – overstorey;
- density/basal area – woody species;
- foliage projective cover – understorey;
- species presence and abundance – ground stratum; and
- recruitment of woody species.

Goat culling commenced 12 months after establishing the monitoring sites. We therefore got the ‘baseline’ monitoring done and one round of monitoring in which there was grazing by the ‘full compliment’ of goats in the unfenced plot compared to the exclosures. From October 2007 until December 2011, 2680 goats were culled by helicopter and ground shooting, with the help of Judas goats. The majority of the goats were culled between July 2007 and the second monitoring period in July 2008. The goat population is now estimated to be about one tenth of its original size.

Given the time available we will look at some of the results from the woodland plots – those being of most interest with respect to koalas – and briefly at the lantana shrubland (“grassland”) plots.

Woodland plots

Progress is being made towards our goals. The biomass of the understorey and the ground cover have improved markedly with the removal of goats and with better seasons (Figures 1 and 2); herbaceous species richness has markedly improved with both fencing (i.e. exclusion) and culling. The increase in understorey biomass in the woodland from 2007 to 2009 was significant in the exclosure and open plots. Percent bare soil remained fairly similar (5-6%) in the exclosure from 2006 to 2008, but then consistently improved (i.e. there was less bare ground) – to <1% in 2010. In the open plot the percent bare soil more than doubled from 2006 to 2007 before goat culling commenced but it improved in 2008 and 2009, and by 2010 it was the same as in the exclosure. This provides good evidence that goat culling and exclusion via fencing are reducing the impacts on ground stratum cover and biomass.

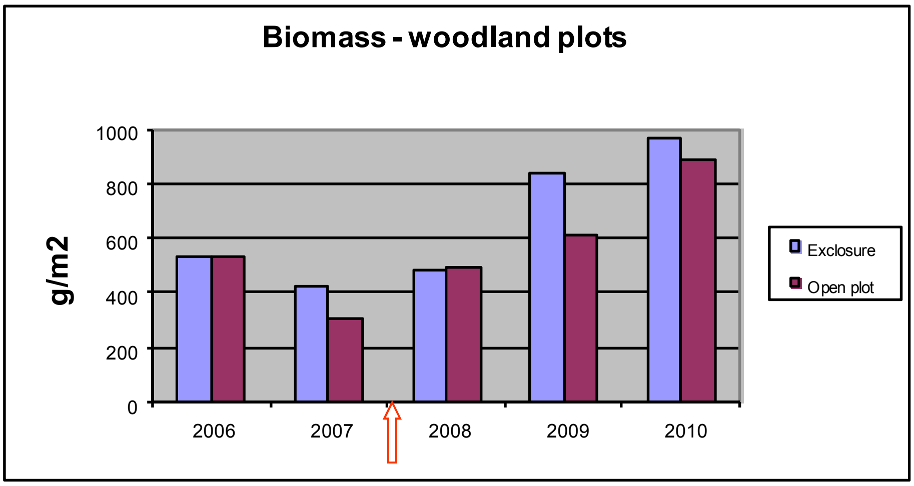

Figure 1 Woodland plots: change in biomass in the exclosure and open plot over time. Red arrow indicates when goat culling commenced (October 2007).

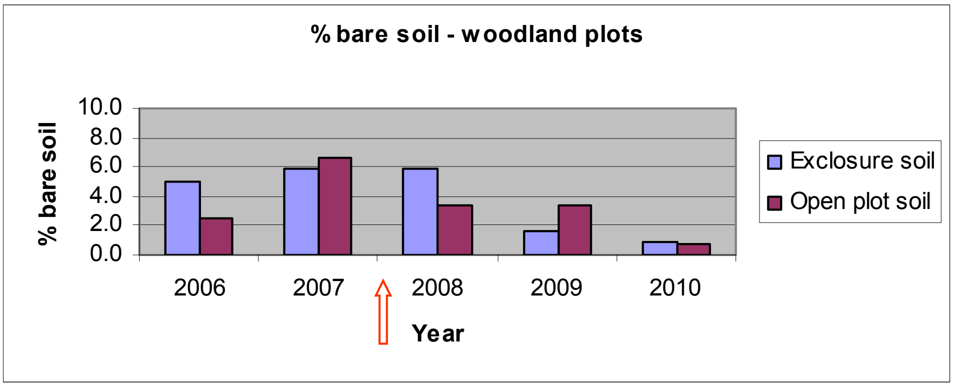

Figure 2 Woodland plots: change in ground cover in exclosure and open plot over time. Red arrow indicates when goat culling commenced (October 2007).

The first Queensland blue gum seedling seen in a decade was found at the woodland site in 2009. Since then a number of seedlings have been found across the island. With one exception however, all of the seedlings found in the monitoring quadrats were rainforest species (predominantly *Cryptocarya triplinervis*) or red ash (*Alphitonia excelsa)* which can be considered a rainforest pioneer. The one exception was a bloodwood seedling found in the exclosure quadrats in 2010. The number of rainforest seedlings in the quadrats was found to increase as soon as grazing was excluded by fencing or reduced by culling (Figure 3).

In summary, understorey biomass, ground cover and herbaceous species richness have all improved in the woodland with goat exclusion or culling but rainforest encroachment occurred quickly once grazing was removed or reduced. The 2011 monitoring season was missed but those who have seen the woodland site since 2010 say that the rainforest has expanded markedly within that 12 month period.

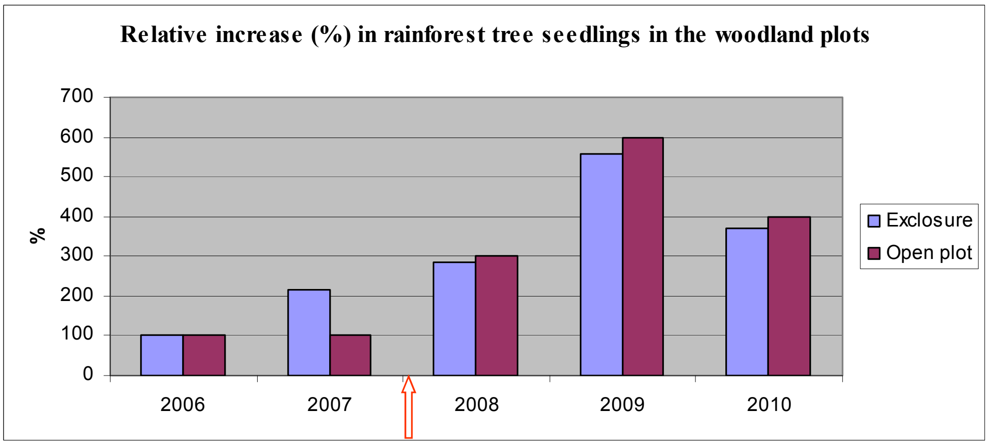

Figure 3 Woodland plots: relative increase in rainforest tree seedlings in the exclosure and open plot over time. Red arrow indicates when goat culling commenced (October 2007).

Lantana shrubland ("grassland") plots

Excluding grazing and conducting goat culling had a positive effect on the biomass and cover of herbaceous species – in particular grasses – and herbaceous species richness. The biomass increased significantly in the exclosure between 2007 and 2008 but remained largely unchanged in the open plot until 2010, with significant differences between the open and closed plots in 2008 and 2009, but not in 2010 (Figure 4). There was a dramatic decline in the amount of bare soil in the exclosure (12.5% at establishment in 2006 to 0% in 2009), whereas the amount of bare ground almost doubled in the open plot in the year prior to culling (7.5% to 13.3%). Bare ground in the open plot markedly improved after culling commenced (1.7% in 2010) (Figure 5). By 2010 goats were being seen in ones and twos rather than in groups of 40+.

There was an increase in grass species richness with grazing exclusion and goat culling. When the project began there were two to three grass species in the plots and by 2009/10 there were seven to eight species. Mean percentage cover/m^2 of *Aristida gracilipes* (the dominant grass species in both plots throughout the period of the project) in the exclosure increased from 28% in 2006 to 85% in 2009 with a decline to 68% in 2010. In the open plot its mean percentage cover/m^2 was 53-58% prior to culling but rose steadily to 90.25% in 2010 (Figure 6). *A. gracilipes* and lantana remained the most common species in the open plot in 2010 but in the exclosure the most common species were *A. gracilipes* (67.5 %/m^2), blady grass (50 %/m^2) and lantana (20.8 %/m^2).

Blady grass is in fact the standout species at present in terms of recovery – it had all but disappeared from this site and was severely reduced elsewhere. In the exclosure its mean percentage cover/m^2 increased from <0.1% to 50% (Figure 7) but remained at <1% (2009 and 2010) in the open plot. It took two years of grazing exclusion to start to see any obvious recovery of blady grass but thereafter recovery was rapid and by 2010 is was overtopping the lantana (Figure 8). Neither dense lantana nor dense blady grass would be easy for a koala to move through.

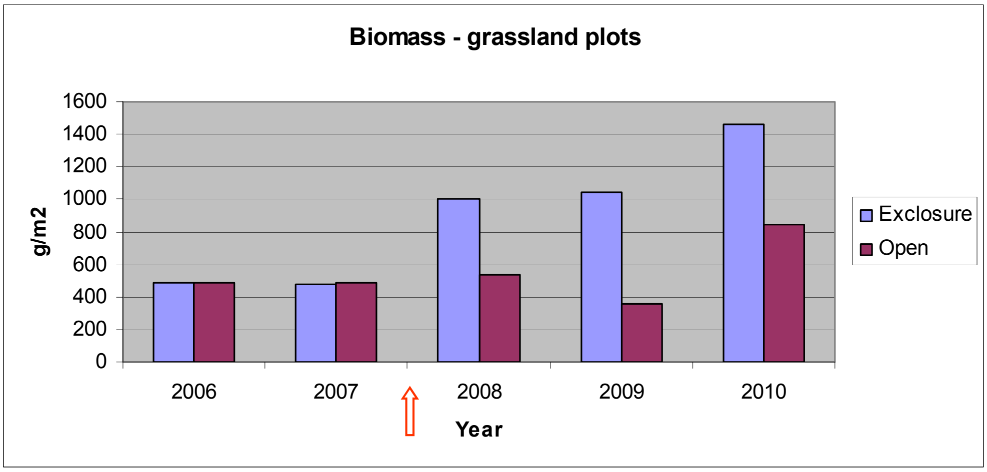

Figure 4 Lantana shrubland ("grassland") plots: change in biomass in exclosure and open plot over time. Red arrow indicates when goat culling commenced (October 2007).

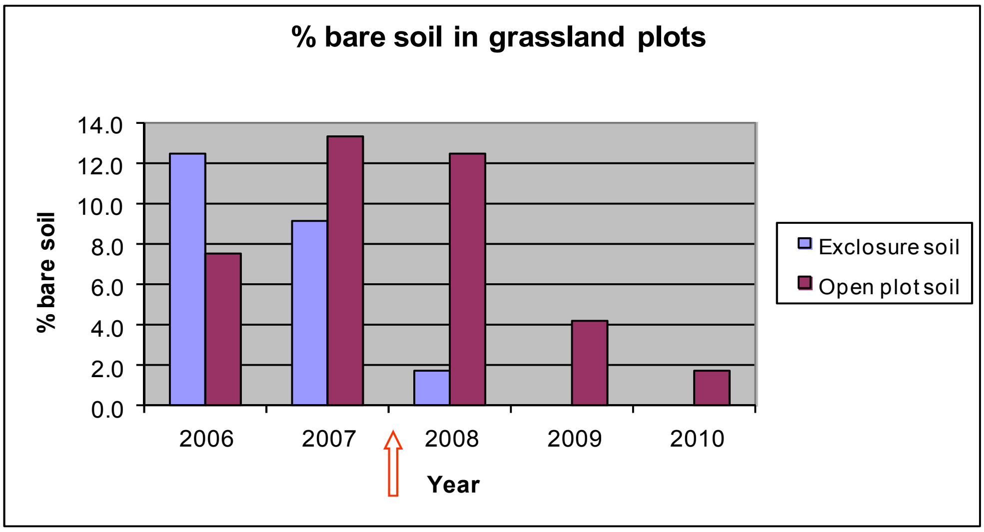

Figure 5 Lantana shrubland ("grassland") plots: change in ground cover in the exclosure and open plot over time. Red arrow indicates when goat culling commenced (October 2007).

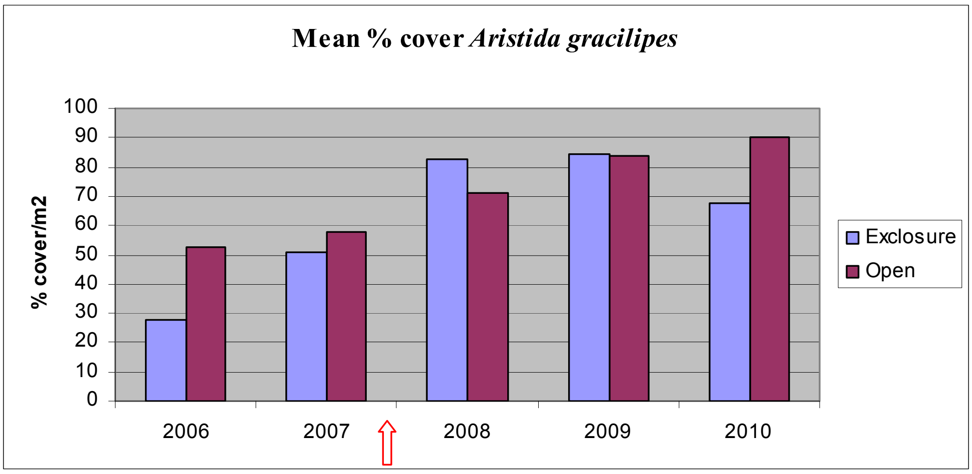

Figure 6 Lantana shrubland ("grassland") plots: change in mean percentage cover of *Aristida gracilipes* in the exclosure and open plot over time. Red arrow indicates when goat culling commenced (October 2007).

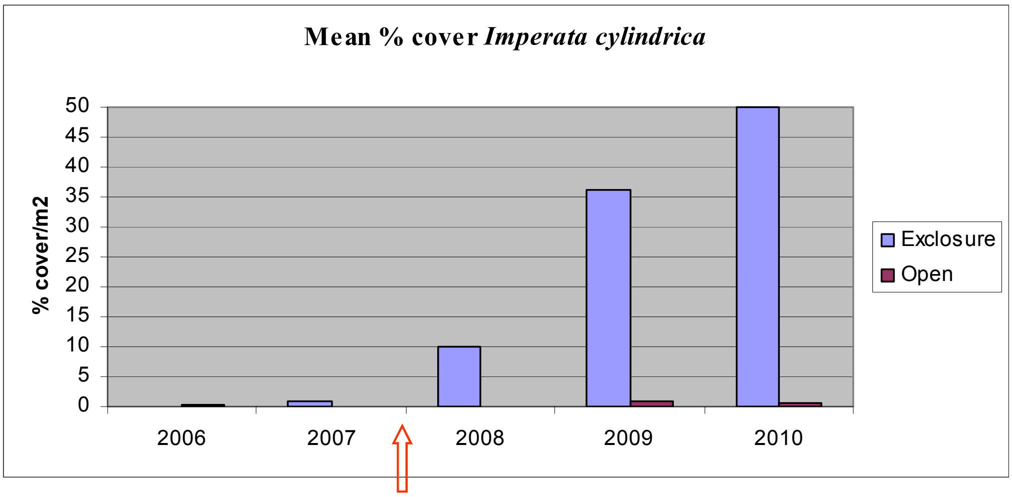

Figure 7 Lantana shrubland ("grassland") plots: change in mean percentage cover of blady grass (*Imperata cylindrical*) in the exclosure and open plot over time. Red arrow indicates when goat culling commenced (October 2007).

Conclusion

So to sum up: Is killing goats and burning bush the answer for the two objectives of management?

Already the benefits of goat culling are visible, including increased ground cover and biomass, decreased bare ground (and therefore erosion), increased native species richness, recovery of native herbaceous species and increased recruitment of native woody species including Queensland blue gum. Aspects of goat removal that are not positive include the enhanced recruitment of rainforest species and liberation of lantana in the woodlands.

Figure 8 Lantana shrubland ("grassland") exlosure. Left: 2006; Right: 2010.

Goat culling alone will not be sufficient to maintain and restore ecosystems and ensure the long-term survival of the Queensland blue gum woodland habitat and hence, the koala population. Fire will be needed to prevent the establishment of rainforest in the woodland, particularly as goats are no longer removing the rainforest seedlings, and to provide suitable habitat conditions for eucalypt regeneration. Fire management is also needed to help restore species diversity in the grasslands and to facilitate lantana control. Chemical control of lantana is an option to reconsider in the management regime together with biological and mechanical control.

The long-term health of the ecosystems on St Bees Island and the long-term survival of the koala necessitate goat culling and judicious fire management.

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Visions of the future: management plans

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The Department of Environment and Resource Management (DERM) is currently in the process of preparing a management plan for the Mackay Islands. The objectives of this short presentation are to provide a common understanding about management plan and process, clarify the current situation with the Mackay Islands Management Plan, and share information about koala management on specific Mackay Islands.

The place of management plans in the Queensland Government planning framework is depicted in Figure 1. Legislation is in place in Queensland that requires the implementation of management plans for all national parks. The DERM Strategic Plan 2011-2015, Queensland Parks and Wildlife Service (QPWS) Master Plan, and QPWS Management Plans sit under the legislation. Management Plans last for about ten years and should then be reviewed and/or rewritten.

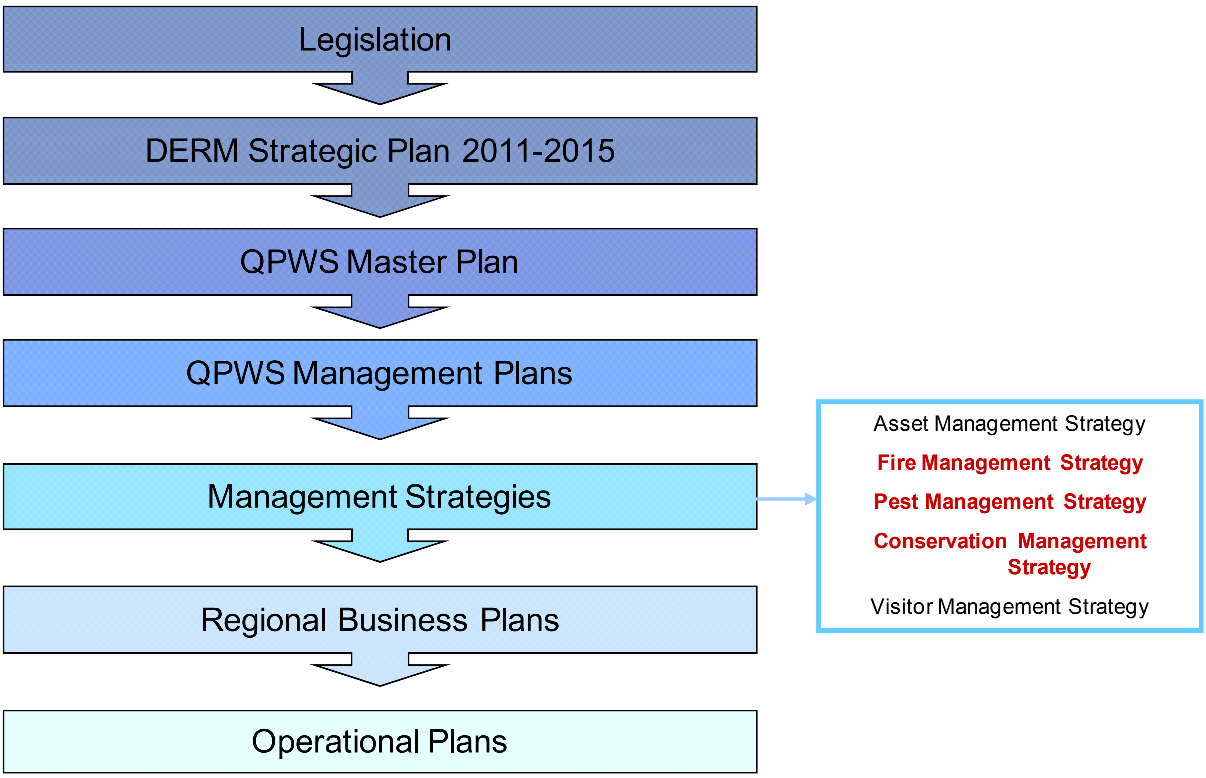

Figure 1 Queensland Government planning framework.

As of February 2012 the Mackay Islands don't currently have a management plan. Newry Island did have a management statement in place and it is being reviewed during this process. Feeding into the management plan are detailed management strategies (for example: asset management, fire management, pest management, conservation management, and visitor management strategies). The management plan in turn drives regional business plans and operational plans.

Under the Queensland *Nature Conservation Act 1992* the Minister (for the Environment) must announce intent to plan and call for public comment. The management plan drafting begins and lasts about 12 months and then a draft plan is released by the Minister. The plan is always the Minister's plan because it sits under the Act. Usually within around six months a final plan is released. There are two formal consultation processes – one when the Minister announces intent to plan and a second public comment on draft plan.

This plan will cover seven national parks and a conservation park (Figure 2) – Newry Islands National Park, Smith Islands National Park, Brampton Islands National Park, South Cumberland Islands National Park, Percy Isles National Park, Northumberland Islands National Park and Yuwi Paree Toolkoon National Park and Middle Percy Conservation Park. The Mackay Islands Management Plan will also take into account marine values in the coastal waters.

Management planning considerations for koala conservation on islands

The aim of management planning for the islands is the long term survival of the koala populations on the islands. Considerations include:

- Habitat requirements
- Population control/enhancement
- Will climate change have an impact? If so, how much?
- Are management actions impacting on the species or habitat?
- What knowledge gaps does DERM have? Where does research need to be focused?

Planning and consultation timeline for the Mackay Islands Management Plan

We try to encapsulate how we want management to progress in the national parks so that it provides direction for the government for the next ten years. The management plan will set the strategic direction for how these islands and the adjoining waters will be managed into the future. In 2011 the public comment on the Minister's intent to plan took place and approximately ten submissions were received. The Minister approved draft development of the plan, and planning started in August 2011. A draft will hopefully be approved by August 2012 and will be released for public comment at that time. The final plan will potentially be released in early 2013. Formal consultation will happen on the draft plan but informal consultations are also welcomed throughout development of the plan.

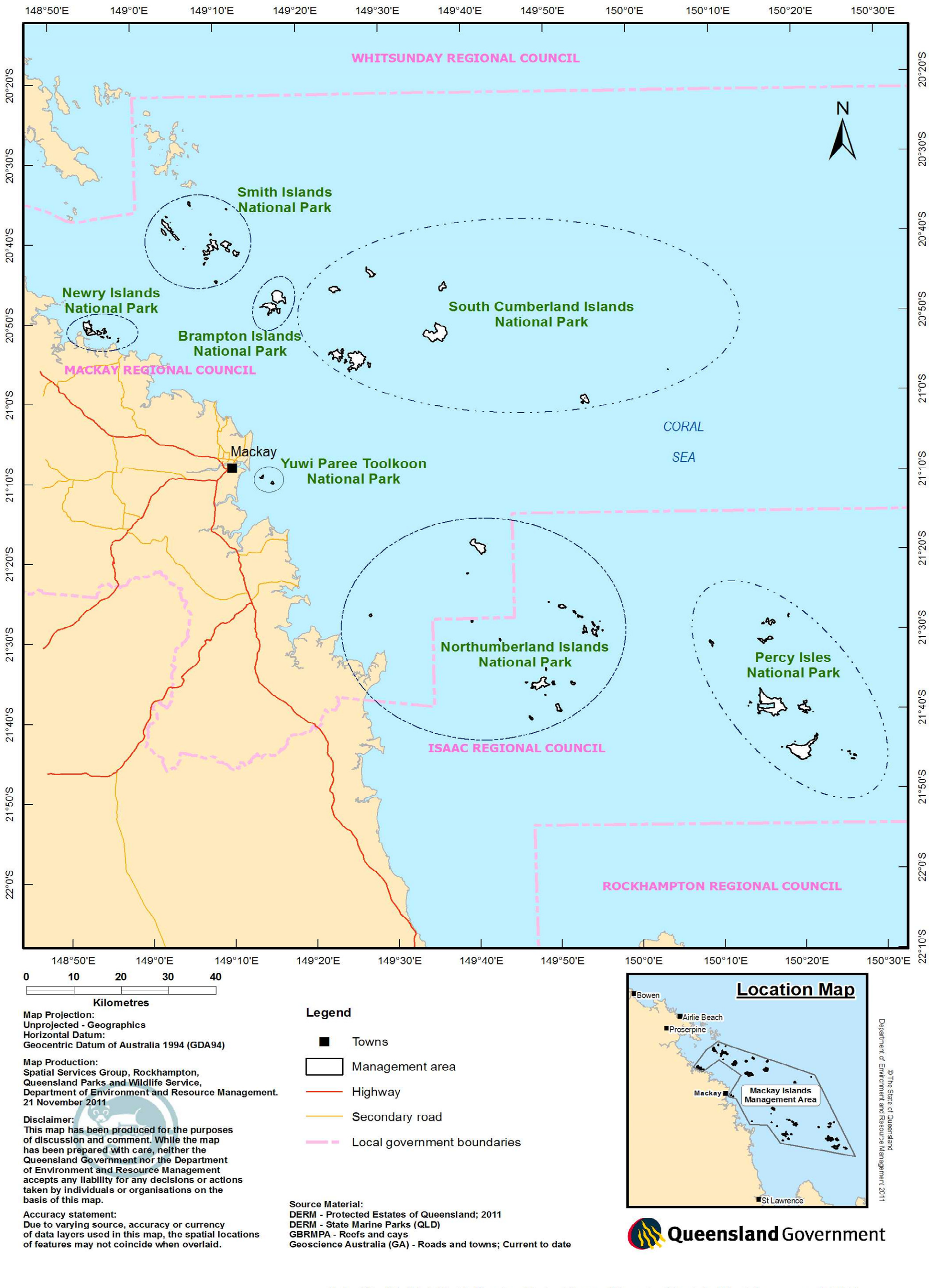

Figure 2 Mackay Islands Management Area.

WORKSHOP SESSION 2: Planning and management of koala habitat on Central Queensland islands

The limitations to management of koalas on the Central Queensland koala islands were associated with (a) competing priorities in park management, and (b) the relative remoteness of these islands. Four key issues were identified as:

1) maintaining prioritization and resourcing at state and commonwealth government levels;
2) logistical constraints to monitoring (e.g. access and equipment transport for both managers and researchers);
3) agreeing strategic frameworks (facilitated by a koala islands management plan); and
4) management of inappropriate access.

The expert panel identified priorities for research and monitoring in all of Queensland's koala islands as:

- access to and sharing of facilities and infrastructure on the islands;
- understanding the value of the central Queensland island koala populations at the state and national level;
- undertaking intensive island-based research to provide baseline data for planning and management,
- assessing the vulnerability of these island koala populations to disease;
- recognizing the importance of the islands for studies on climate variability and medium term change;
- demonstrating the importance of introduced island populations as laboratories for fundamental research and conservation management;
- investigating the dynamics of Central Queensland island koala populations and contrast with the dynamics of island populations from southern Australia – especially with regard to resource limitation;
- consider the potential for advantageous gene selection on the koala islands (e.g. tendency to reduce tooth wear); and
- highlight the program on St Bees Island as a case study of a successful research/management partnership to facilitate state resourcing of monitoring and management on the other koala islands.

Theme 3. CAPTIVE MANAGEMENT AND KOALA CONSERVATION

Koala management and research at the San Diego Zoo

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Research on koala zoo populations can support and work in conjunction with *in situ* koala research projects. Over the last five years San Diego Zoo has been involved in some very exciting research projects including those being run in central Queensland.

There is a long history of koalas at San Diego Zoo. The first animals were received in 1925 as a gift from the children of Sydney to the children of San Diego. To get such an iconic species was a big deal for the zoo at the time. The zoo has a very successful record with management and breeding of koalas in a zoo setting. San Diego Zoo continued to exhibit the species throughout the years but it was in the mid-1970s that the zoo realised the importance of the species as an ambassador for all koalas and their habitat.

In 1976 a new import of animals arrived that formed part of the founder animal base for the current North American and European populations. With the new imports came new husbandry management of the koala population that involved heavy data collection such as weekly weights, female oestrus cycles, all breeding events regardless of whether or not they were successful, and the types of breeding interactions. Data were collected on all joeys from birth through emergence, including all developmental milestones. The data were collected and maintained but not analysed until 1983 when San Diego Zoo took a new direction and created the “San Diego Zoo’s Koala Education and Conservation Program”. The program created satellite colonies outside of the San Diego colony for population sustainability (for example in case of disease), and provided assistance to koalas in the wild by becoming a voice-piece for the species, increasing public education opportunities and raising funds for *in situ* conservation support. The program has now been running for almost 30 years and has supported some great field research. In the last couple of years there has been a huge emphasis on the importance of captive zoo colonies which play an important role in the future with wild koala populations.

An important part of maintaining the koala colony is keeping the Koala Studbook. The studbook is a wonderful way to maintain genetic viability to figure out koala pairings. Using the data in the studbook, the zoo decided to do a mate-choice project with the koalas. Years of data on history, clipboards of data regularly collected on each koala, and the studbook were used. The studbook provides information on lineages, which koalas have been paired, the resulting offspring of these pairings, the demographics of zoo population (including the North American population and the European population) which can be used to develop breeding recommendations (Table 1, Figures 1 and 2). Fantastic research can be done for mate choice using this information.

Table 1 Studbook data.

	North America	Europe	Total
Population Size	21.24.3 = 48	11.15.0 = 26	74
Participating Zoos	8	7	15
2007 Births	3	5	8
2007 Deaths	6	5	11
2008 Births	4	0	4
2008 Deaths	10	3	13
2009 Births	9	4	13
2009 Deaths	5	4	9
2010 Births	5	1	6
2010 Deaths	7	5	12

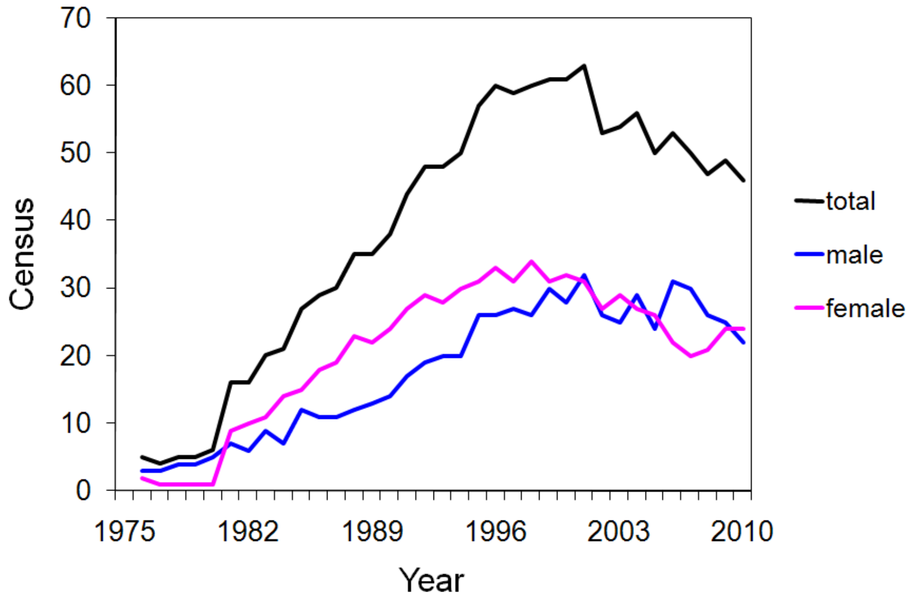


Figure 1 Studbook census data.

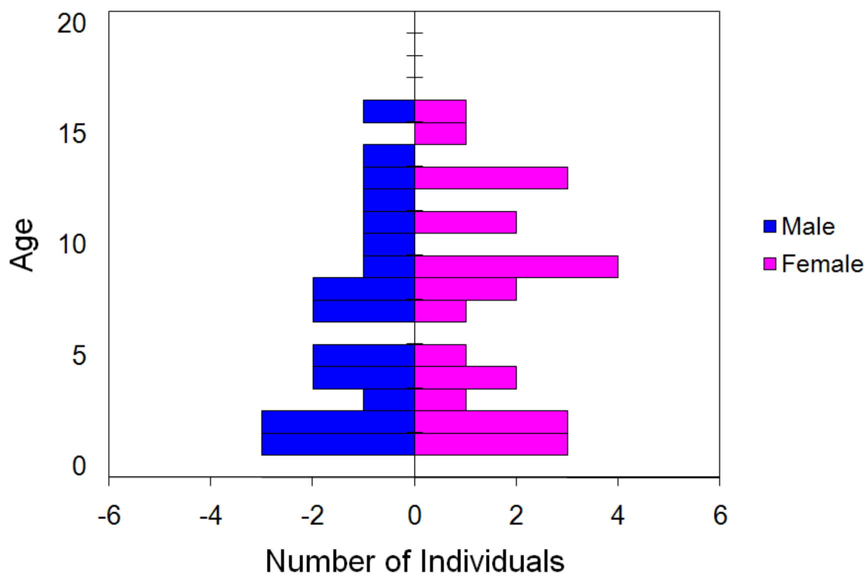


Figure 2 Studbook age data.

The first big publication was all of the long term data from 1980s onward to 2002, which was used to try to decipher if there was mate choice in the breeding colony, and what successes were they having. Were there ways to make it more efficient? Koalas are not a simple creature, they are always complex. The animals sleep most of the time, their births are seasonal, and there are differences in the success of copulation. About half of first time pairings did not result in copulation (Figure 3).

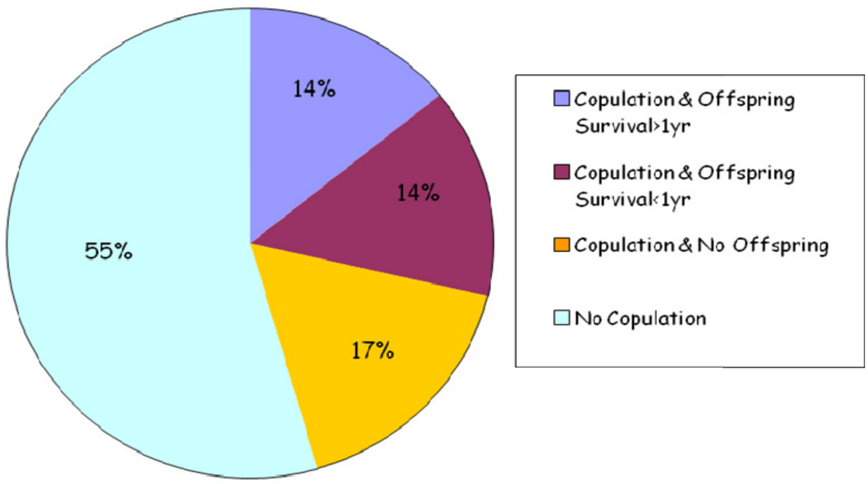


Figure 3 First time pairing success rates.

A lot was learned from watching the multiple koala pairings over and over again. It was deemed that the female koalas seemed to be making a choice about copulation, so the research branched off into looking at male attributes, the focus being on what the females were picking up on about the males. The relative age difference between mating partners was an influencing factor in copulation. Koalas closer in age were significantly more likely to copulate upon first pairing. The direction of the age also significantly affected the probability of copulating the first time a pair was exposed to each other – with pairs much more likely to copulate the first time around if the male is older than the female (Figure 4). Long term pairing data are available for the San Diego Zoo colony (Figure 5, 6 and 7), as are long term data on birth rates (Figure 8).

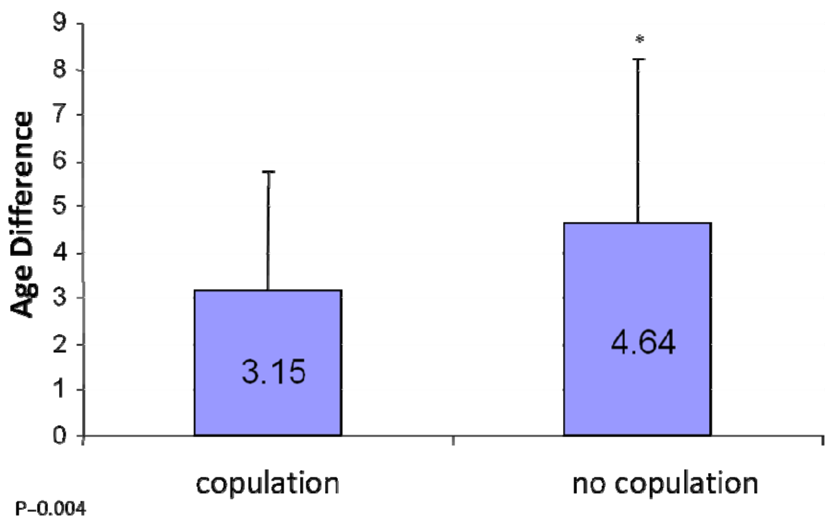


Figure 4 Age difference between male and female based on outcome.

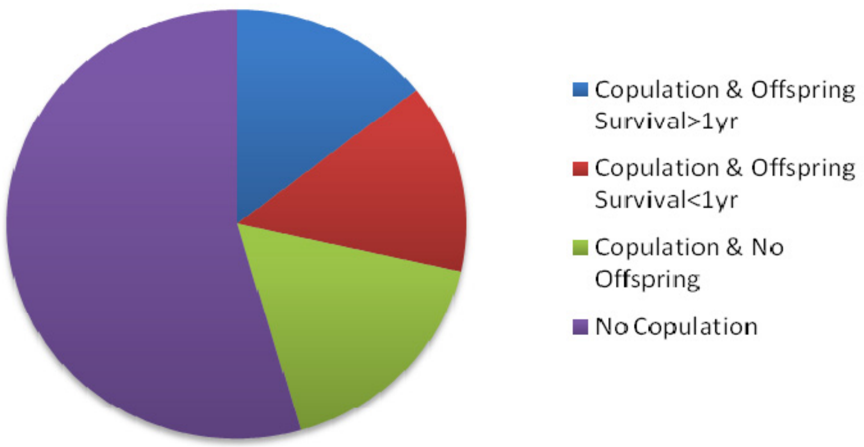


Figure 5 Long term data on first time pairings.

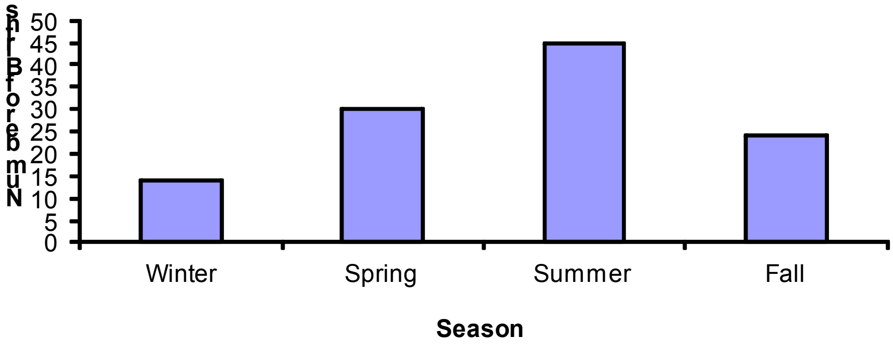


Figure 6 Long term data: all koala births from 1984 to 2002.

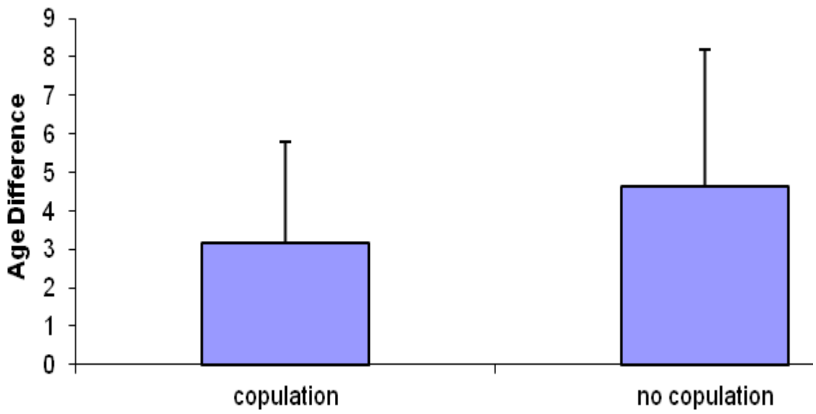
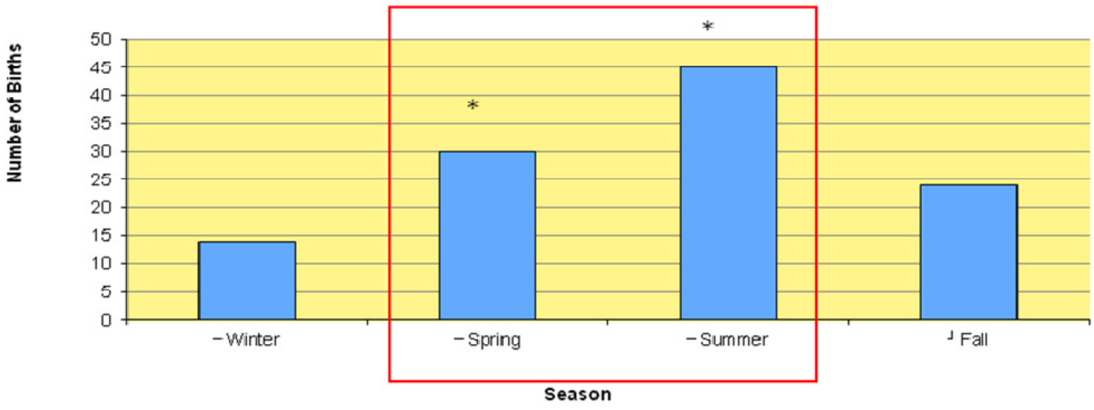


Figure 7 Long term data: age difference between male and female based on outcome.



P<0.001

Figure 8 Koala births at the San Diego Zoo (1984-2002). Note that these are North American seasons and reversed in Australia.

Koalas are solitary in the wild and how they find each other during the breeding season is part of the ongoing study at San Diego Zoo. William Ellis joined the zoo as a post-doctoral fellow and started to take some of the things the zoo was doing and bring them out into the field. We were able to go out and collect scent samples from animals in the field and compare them to captive animals (Figure 9) – William could then ask Jen what attributes he should be looking for in males.

This led to further collaborative work including William's remote sensors to record koala bellows on St Bees Island. A sensor has been set up at San Diego Zoo and it can be used to compare between the zoo colony and the St Bees colony that William is studying – it makes both research sets more robust.

The research coming out of zoos on captive animals can't always be directly compared to wild populations. But there are difficulties in getting out into the field and catching animals – zoos make it easier to trial research before applying it in the field. For example in the koala bellow research the zoo sensor has been helpful in determining the best location for the sensor, and information such as how many bellows should you be hearing from a certain number of koalas.

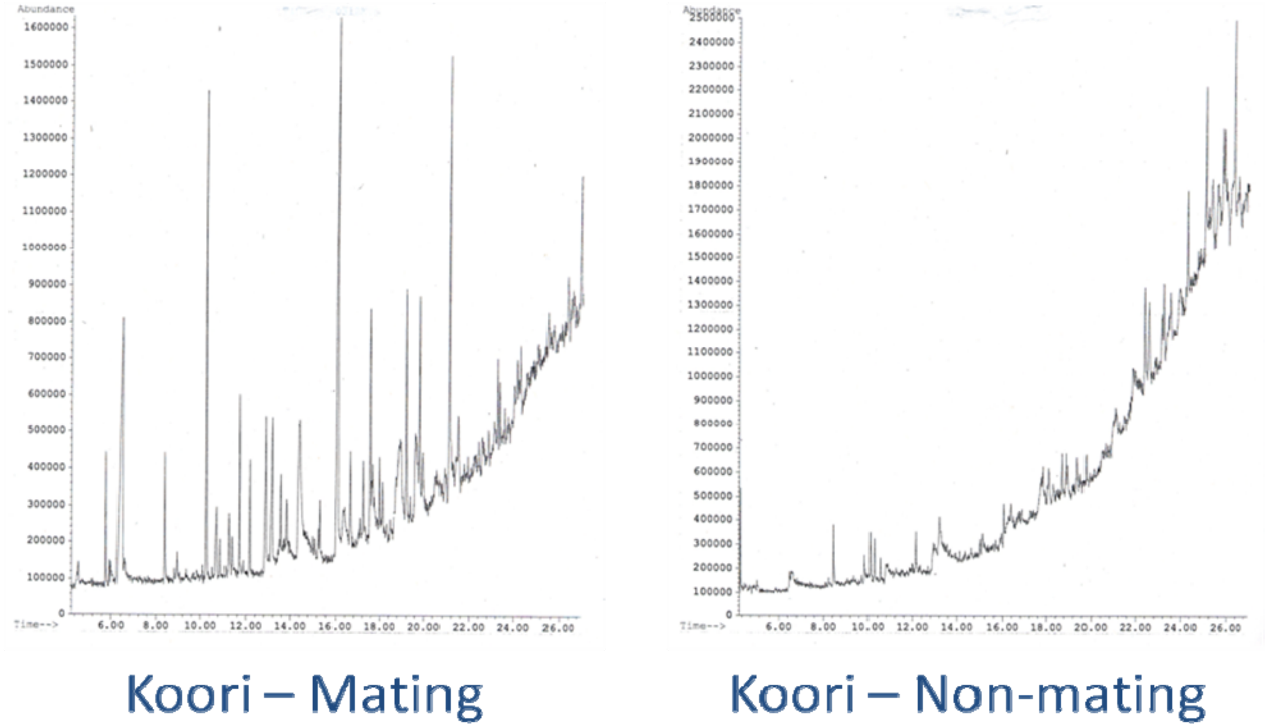


Figure 9 Mating season and scent gland profiles.

Overview of the captive koala population based in Zoo and Aquarium Association institutions and Dreamworld's perspective on koala conservation

Al Mucci

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Overview of captive population

A large number of Zoo and Aquarium Associations (ZAA) exhibit koalas as part of their collection. In Australia, most zoos exhibit koalas. However, the relationship extends far beyond display for educational purposes with many members playing a role in rehabilitation and release of animals, in supporting koala research conservation programs as well as providing a reservoir of husbandry and life history expertise that may be applied in wild scenarios.

The Australasian Species Management Program (ASMP), the species management arm of the ZAA, oversees two international studbooks for koalas. The southern koala studbook covers *Phascolarctos cinereus victor* and is maintain by Sjoukje Vaartjes at Melbourne Zoo. The northern koala studbook covers *P. c. adjustus* and *P. c. cinerus*, with Michele Barnes at Dreamworld maintaining the Australian records and Paul Andrew based at Taronga Conservation Society Australia maintaining data for koalas held overseas.

In 2000 the decision was made to manage *P.c. victor* and *P.c. adjustus / cinereus* separately. This decision was made in the context that captive koalas were not being bred for release back into the wild but to meet captive requirements only, therefore breeding was aimed at: maximising heterozygocity within the species; maintaining long-term genetic viability; avoiding inbreeding; and not producing maladaptive phenotypes. The decision to maintain two separate captive populations was based upon South Australian/Victorian wild populations exhibiting low levels of genetic variability compared with those from further north. Such southern-origin koalas are therefore less than equivalent to animals from the north as founders of a captive population. As a result, a captive population founded from Queensland and New South Wales origin animals is likely to retain higher levels of genetic variability if segregated from southern-origin animals. This position was endorsed by the Taxon Advisory Group, the ASMP and the Department of Sustainability, Environment, Water, Populations and Communities (SEWPAC) (Andrew and Wilcken).

The primary purpose of the studbook has been to provide advice to regulatory bodies (SEWPAC) on suitability for individual koalas to be exported overseas based on their relatedness to koalas already based overseas. More recently considerable effort has gone into updating the Australian records which will allow a thorough assessment of the Australian captive population in member zoos. Currently there is no coordinated program for the breeding of koalas in member zoos. It should be noted then that data from the studbooks should be interpreted with care.

Northern koalas

A preliminary review of the northern koala studbook indicated that the *current population* is 216.313.15 (544 koalas) and the *planned population* is 217.380.45 (642 koalas) (ASMP Regional Census and Plan).

The current population primarily consists of captive born animals (87%). Only 5% of the population is wild born and there is 8% of unknown origin (Studbook).

The studbook indicates that there are:

Founders = 57, Potential Founders = 11 additional;

Genetic Diversity (GD) = 0.9729, Potential GD = 0.9880;

Mean F = 0.0133, MK = 0.0271.

These figures indicate that the population in ZAA zoos has good genetic potential, with a good number of founders, good genetic diversity, low levels of inbreeding and relatedness.

These figures are based on actual known data with parentage 26% known. The population would benefit from greater attention on pedigree, there are quite a few animals with unknown or uncertain parentage. However through close analysis of the studbook reasonable assumptions are likely to be made in the future to allow for a better assessment of the population's potential.

Demographically there are good numbers held in zoos but in more recent years, not enough animals have been bred to meet demand and to maintain a stable age structure long-term (Figure 1).

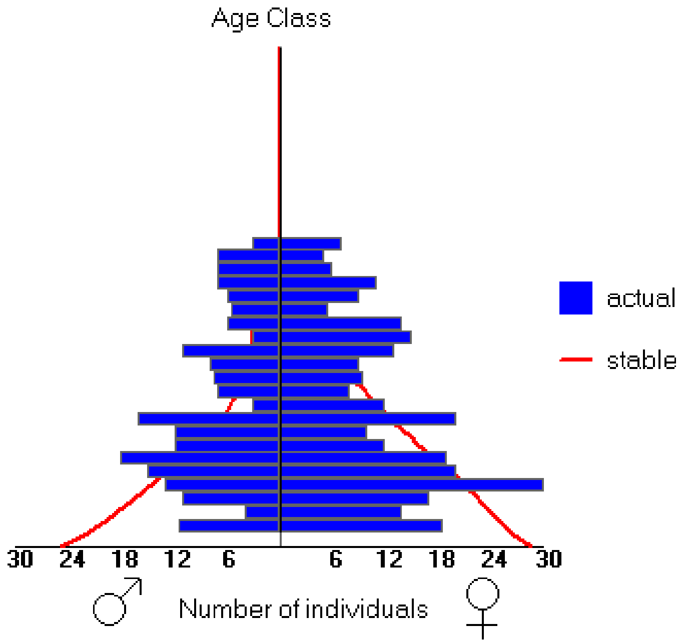

Figure 1 Age Pyramid.

Since the mid-1980s records show breeding levels around the 50 births per year mark. This is a good number to maintain the current population level in captivity (the last three years births have been lower however why this has occurred has not been analysed).

Eighty five percent of offspring lived greater than one year; 14% died before they reached one year old (Studbook). However this figure is not reliable as it is likely early deaths were not reported to studbook keepers for a number of institutions (Figures 2, 3, 4, 5).

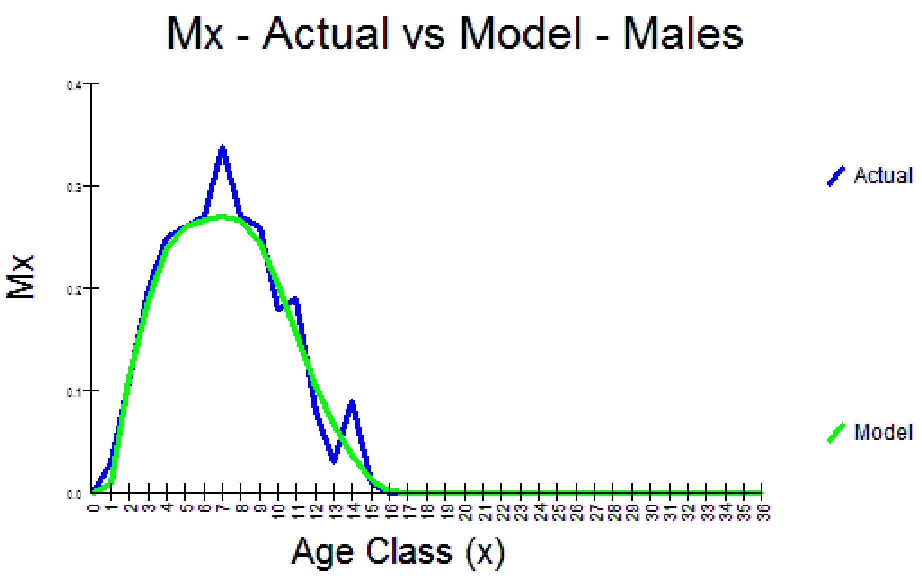

Figure 2 Fecundity for male koalas (Northern Koala Studbook).

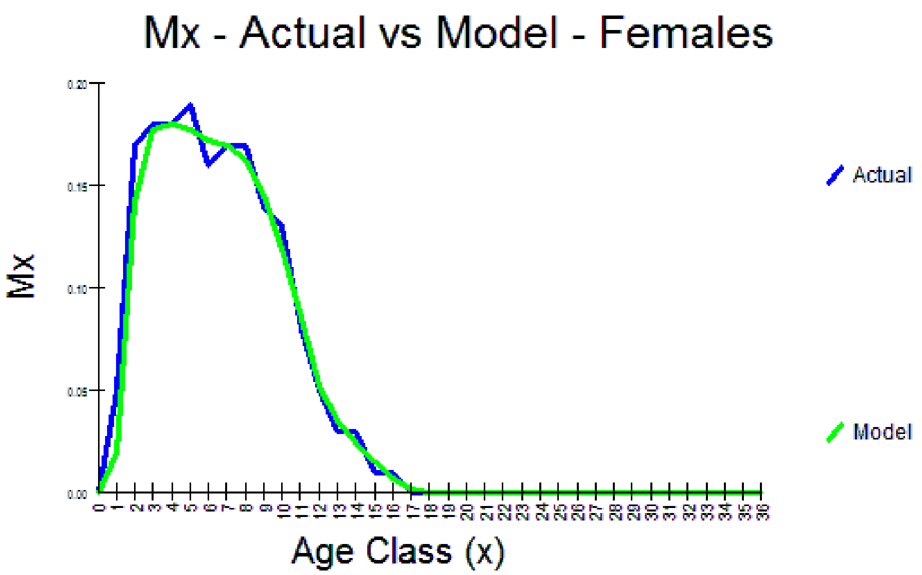

Figure 3 Fecundity for female koalas (Northern Koala Studbook).

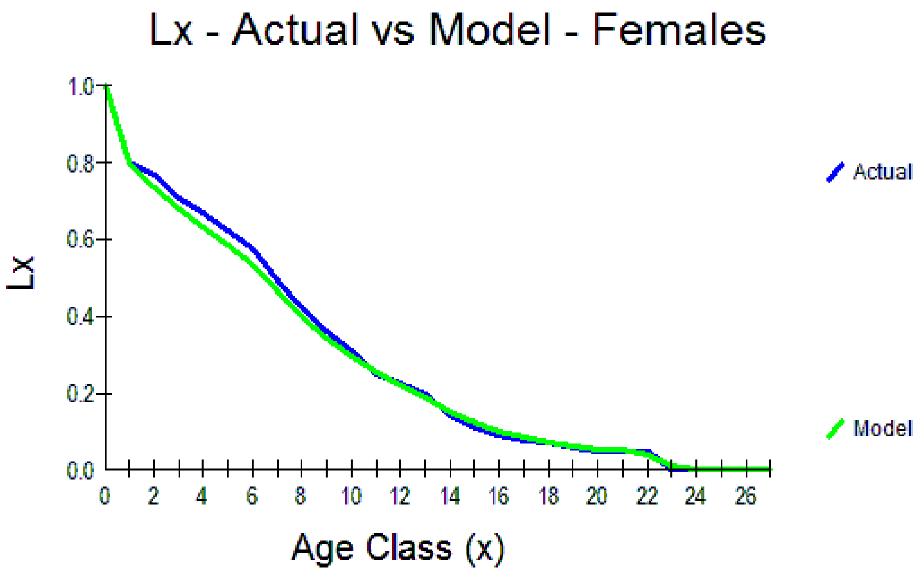

Figure 4 **Survivorship curve (Northern Koala Studbook). Maximum longevity is around 22 years. The data that extends beyond that is unreliable and is currently being investigated. (That is, koalas in the studbook that do not have death dates recorded that should have, or have estimated birth date – usually wild caught individuals).**

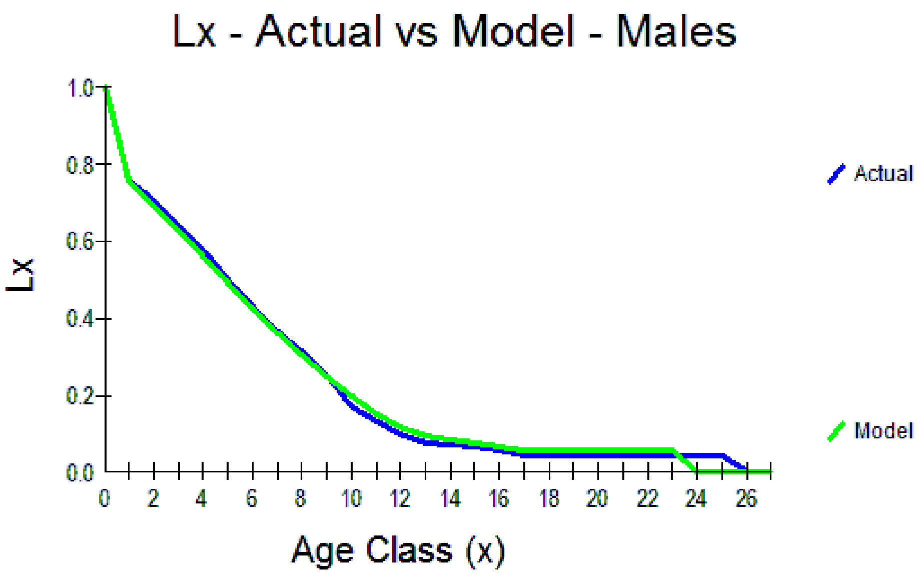

Figure 5 **Survivorship Males (Northern Koala Studbook).**

Southern koalas

A preliminary review of the southern koala studbook indicated the Current Population is 55.62.0 (117 koalas) and the Planned Population is 64.110.4 (178 koalas) (Species Management Program).

This is around 56% wild born and 44% captive born (Studbook).

The studbook indicates there are:

Founders = 34, Potential Founders = 33 additional;

Genetic Diversity = 0.9292, Potential GD = 0.9901;

Mean F (inbreeding) = 0.0530, Mean Kinship = 0.0708.

This population also has good potential with a reasonable size founder base. Genetic diversity has excellent potential with low levels of inbreeding and kinship.

Parentage is 90% known in this studbook.

Future challenges

It should be noted that the koala populations are not currently managed but they are genetically managed in-house, e.g. Dreamworld is assisted by The University of Queensland in genetic management of its internal population. With wild populations in some areas declining like South East Queensland, captive populations can play a significant role as a conservation resource.

ZAA institutions are well positioned to deliver:

- funding opportunities to support conservation outcomes;
- captive populations that can enhance research;
- advocacy for the koala.

Koalas internationally

Koalas from time to time are exported to zoos overseas. There are stringent regulations with movements overseas with zoos required to sign an ambassador agreement and meet the koala export conditions overseen by SEWPAC. There is a movement towards establishing populations overseas that are more sustainable than they have been in the past. That is, to supply sufficient unrelated animals to ensure that less supplementation from Australia is required to avoid inbreeding etc. There is an American studbook and a Japanese studbook for northern koalas. These records are updated regularly by the international studbook keepers based in Australia.

A small population of southern koalas can be found in Israel, Japan and USA (6.2.0).

The northern koalas are held in a number of facilities in Japan (around 27 animals – 2009 data) and USA (48 animals – 2009 data) and there are a few animals in Europe (9), Taiwan (7), China (18), Thailand (3).

Since 2002, 39 koalas have been exported to overseas zoos.

Advocacy and collaboration challenges

The following are important topical issues for discussion purposes that require innovative and strategic solutions:

- better understanding of disease;
- a disparity amongst Australian states on the value of the koala;
- a national standardised monitoring methodology to identify trends in koala populations.

Further, the Federal Government needs to take a lead role on the implementation of the National Koala Conservation Strategy. This requires adequate resources, funding and promotion.

Acknowledgements: Paul Andrew, international studbook keeper for Northern koalas, Michele Barnes, Australian studbook keeper for Northern koalas. Sjoukje Vaartjes international studbook keeper for Southern koalas.

Reference

Andrew, P. and Wilcken, J. *Monotreme & Marsupial Taxon Advisory Group Discussion Document Management units for captive Koalas*. Zoological Parks Board of NSW, Australasian Regional Assoc. of Zoological Parks & Aquaria.

The role of captive koalas in koala conservation

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In this paper we would like to draw your attention to two relatively simple ideas; (1) The importance of captive koalas for understanding fundamental biology; and (2) The role of captive koalas in novel conservation strategies, where more intensive management is required.

The need for fundamental biology in koala conservation

In a world that is currently obsessed with theoretical ecology, trying to obtain support for the fundamental scientific disciplines or for descriptive biology is becoming increasingly difficult. This appears to have contributed to a lack of focus on the whole animal and a subsequent dearth of information on basic biology. It is our contention that an over reliance on old or out dated fundamental biology can have serious consequences on mathematical models that have been used to drive conservation policy. Captive koalas have or can play a crucial role in understanding and acquiring this basic information on all aspects of koala biology. For example, our studies of reproductive physiology conducted on captive koalas (Johnston et al., 2000a, Johnston et al., 2000b, Johnston et al., 2004) have shown that the mechanism of ovulation in species is associated with coitus and the possible presence of ovulating substance in the semen; this type of information has a profound impact on understanding mating strategies and therefore, behavioural ecology. Captive koalas have also contributed to our understanding of metabolism, nutrition and disease and been a valuable resource for the development and testing of field based technologies; there are experiments that we can conduct on captive animals that are simply not possible on wild populations.

Example 1 – Measurement of koala stress

In 2010/11, the Queensland Government released funds to investigate aspects of koala disease. There was quite a bit of interest in this money amongst a range of research groups to explore the relationship between disease susceptibility and stress physiology. The primary hypothesis of our work in this area centred around the assessment of faecal cortisol as a measure of stress and the subsequent relationship of this metabolite to the disease status of koala populations. We have conducted similar studies in the southern hairy-nosed wombat (Hogan et al., 2011). Figure 1 shows plasma cortisol secretion of four animals injected with an ACTH agonist (SYNACTHEN) that resulted in an elevated secretion approximately 45 minutes later. We then subsequently collected faecal material from the same animals a day before the challenge and for 7 days later. Faecal hormone analysis for cortisol metabolites resulted in a significant elevation in faecal cortisol 2-3 days later, coincident with gut transit time (Figure 1). Although not shown here, we have also been able to demonstrate an elevated cortisol concentration associated with perceived stressors such as when the animals were handled for weighing. This captive animal study thereby provided the appropriate validation of the wombat cortisol faecal assay.

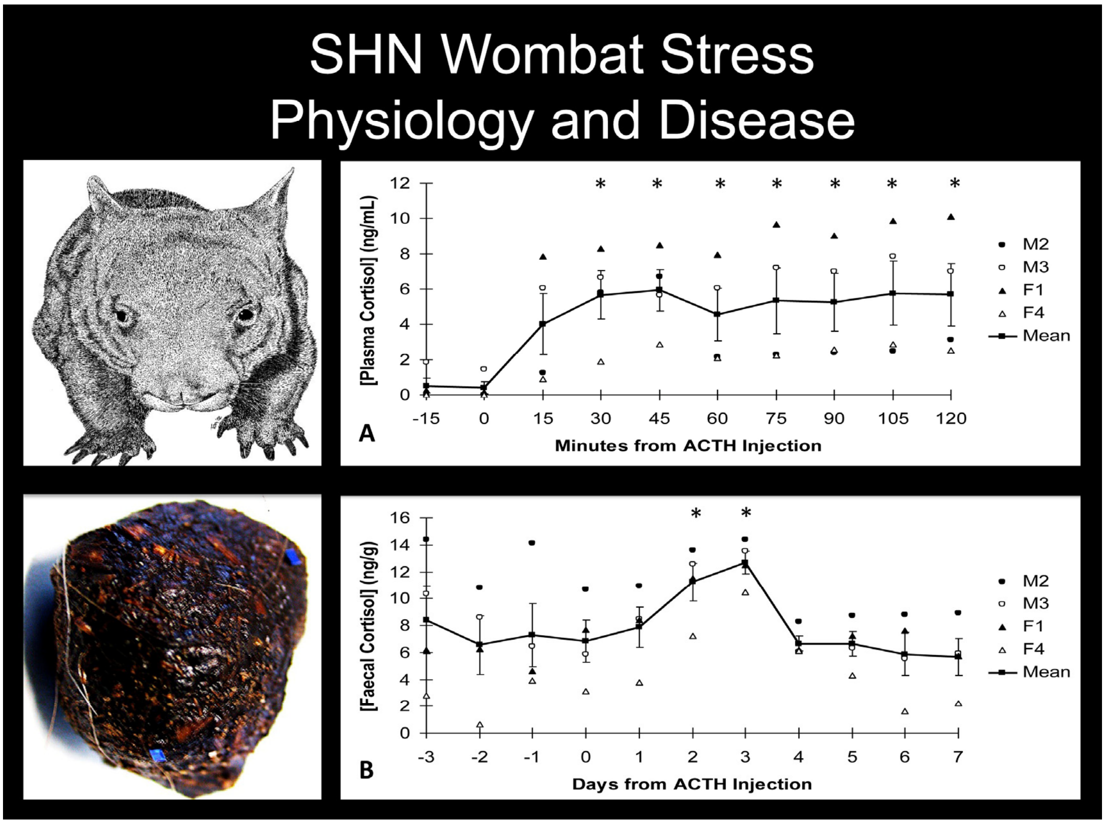

Figure 1 ACTH challenge to induce serum and faecal cortisol in the southern hairy-nosed wombat (From Hogan et al., 2011).

We have recently completed a similar study on koalas at Currumbin Wildlife Sanctuary (Johnston et al., submitted). We administered five koalas with either an ACTH challenge or an injection of saline as a placebo. We then assessed the relative changes in serum cortisol secretion. We also collected faeces for 10 days post injection to account for the prolonged gut transit time in the koala. Our results revealed that while ACTH administration resulted in an elevation of serum cortisol for at least 4 hours post injection, it was not possible to identify a corresponding peak in corticosterone or cortisol in the faeces, consistent with the known gut transit time of the koala. Based on this evidence we suggest that faecal estimates of cortisol and corticosterone are not reliable indices of serum cortisol secretion in the koala and that studies that attempt to use faecal cortisol as an index of stress will need to be conducted with caution. Clearly, this type of research can best be conducted on captive koalas, before it is applied to wild animals.

Example 2 – Koala thermoregulation and climate change

We are currently preparing studies to surgically implant i-buttons or thermal radio-transmitters in the koala to document changes in the core body temperature in order to better define the koala's thermal niche – we believe that this information will allow us to develop a better understanding of the thermoregulatory capacity of the koala and how it might allow the animal to respond to the impact of climate change, especially with respect to the predicted increased incidence of heat wave and drought events. We are particularly interested in concepts of heat load and heat dissipation, to better understand ecophysiology. This will no doubt be important when investigating the effect of climate change on spatial and temporal habitat use; the effect on reproductive physiology (e.g. sperm production) will also be interesting. Remote core body temperature technology currently exists that will allow us to gather this information so that it can also be appropriately fitted into mathematical models. Ellis et al. (2002) have previously shown that koalas utilise more than just eucalyptus food trees in their daily patterns of behaviour and this is likely to be associated with a strategy to dissipate accumulated heat load. We now have the capacity to quantify this phenomenon in terms of its effect on core body temperature. This research, using captive koalas, will allow us to gain a constant image of (a) the heat load of the koala, (b) the available microclimate and (c) the behaviour and physiological responses of koalas to environmental temperature and humidity: three critical aspects to consider when predicting the survivorship of koalas under various climate change scenarios.

It is doesn't take a "rocket scientist" to conclude that studies of fundamental biology are necessary to advance our big picture understanding of koala conservation, but unfortunately, funding for such activity often appears to come a poor second cousin to mathematical modelling. Our frustration is further compounded when these models are seemingly compromised because of an incomplete understanding of fundamental biology. We need to start to re-focus some of our attention back on the whole animal – captive koalas, whether in wildlife parks or in a dedicated research facility, provide an opportunity to do this.

The role of captive koalas in novel conservation strategies

We would like to introduce some alternative ideas about koala conservation that are based on captive koalas and demonstrate how Queensland populations could be used for intensive genetic management of wild koala populations. While zoos and wildlife parks have traditionally aided in koala conservation through their ability to (1) educate the public on koala biology and conservation; (2) promote koala experiences that generate empathy with the species; (3) provide animals and funding for research; and (4) run and fund hospitals for koala care and rehabilitation; perhaps there are other more direct roles that captive koalas can play?

Genetic exchange – the live and frozen genome bank

As koala habitat becomes increasingly fragmented and koala numbers continue to decline, perhaps it is now time to consider more intensive "hands on" management strategies for koala conservation. While this type of activity must obviously be informed by careful attention to the specific genetic and disease status of these populations (to ensure we don't repeat the experience of southern Australia), it is our contention that captive populations can play an important role in koala genetic and population management. These ideas revolve around the central concept of genetic exchange and the functioning of what we have referred to as a living and frozen genome bank (Figure 2). This idea is subsequently formulated on four inter-related genetic management strategies which we loosely term: (1) genetic connectivity; (2) genetic capture; (3) genetic recovery; and (4) genetic propagation.

A genome bank is a simple concept in which captive koala colonies are managed like a bank account as genetic deposits and withdrawals in order to ensure the maximise genetic diversity of fragmented or threatened local populations. Frozen gamete storage provides an opportunity to store large amounts of genetic variability, cheaply and conveniently for prolonged periods of time in liquid nitrogen. This approach can greatly increase the generation interval and dissemination of genetically important individuals. While the idea of a frozen genetic resource is well established in agriculture, and to some extent in certain wildlife species, the development of a frozen genetic resource for the koala has been somewhat hindered to date by our inability to successfully cryopreserve these cells. While we wait for koala gamete cryopreservation techniques to be improved, there is another alternative approach that can also be used to store genetic potential. This involves the use of live captive animals to store and facilitate the genetics of wild animals, via natural captive breeding or artificial insemination. These captive animals then become the repositories of important genetics and can serve as vehicles to facilitate gene-flow. The koala breeds extremely well in captivity and is ideally suited for this style of conservation strategy.

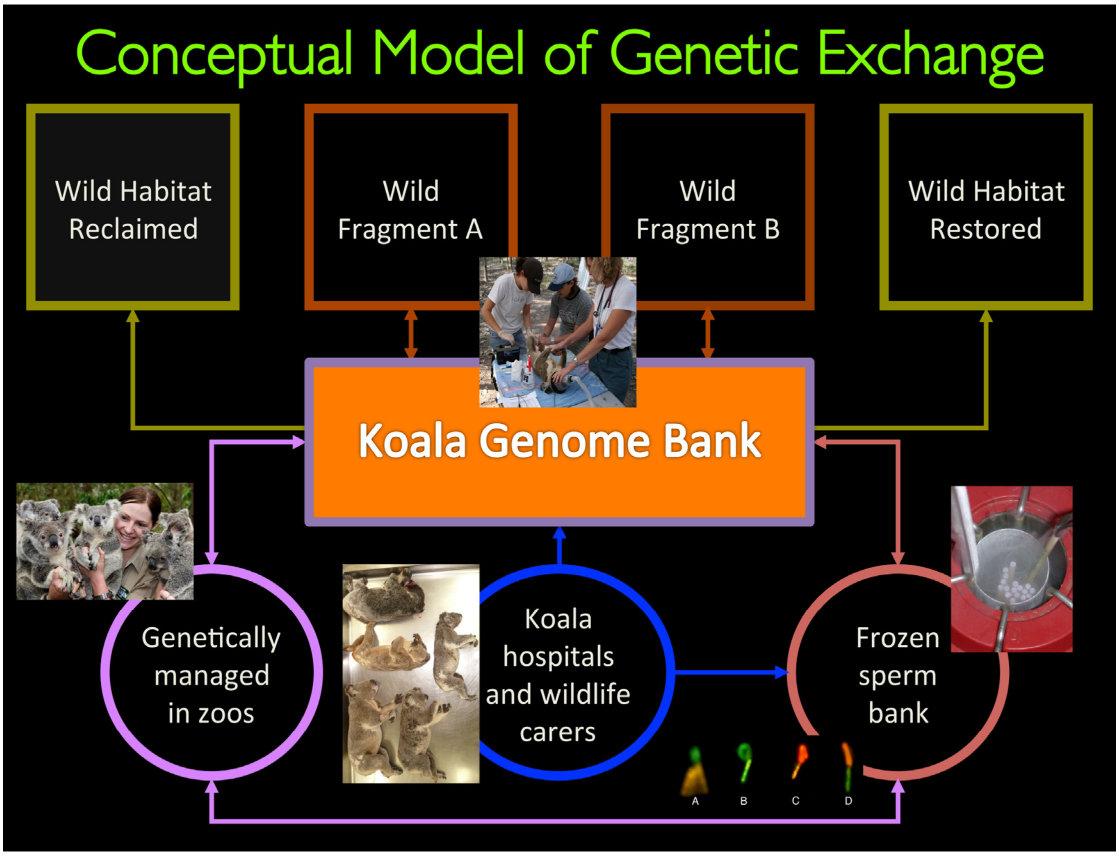

Figure 2 Conceptual model of koala genetic exchange – live and frozen genome bank.

<u>Genetic connectivity</u>

In our concept of genetic connectivity, we envisage wild koalas spending short periods of time in captivity to facilitate genetic exchange between fragmented populations. For example, koalas from respective habitat fragments A and B could be brought together into captivity, bred and released back into their respective fragment. In this way, we not only ensure greater genetic diversity and gene-flow into both fragments but we also ensure the propagation of additional offspring of high genetic worth.

Genetic capture

A closely related idea to genetic connectivity is genetic capture. This might involve the diversion of koalas destined for translocation through a genetic resource bank to make a deposit. During the process of translocation, male koalas could spend a short period of time in a captive facility for the purposes of breeding, or perhaps the semen of these males could be collected in the wild and inseminated into dedicated captive females; in this way their genes would be captured and stored. In the case that the translocation was a failure, we would still have an insurance policy in place for the safe haven of their genetics.

Genetic recovery

From 1997 to 2009 the Queensland Department of Environment and Resource Management reported that 6581 koalas were euthanized in koala hospitals in south east Queensland. This represented an incredible waste of genetic resource, which could otherwise be recovered using assisted breeding techniques. Genetic material in the form of spermatozoa can be recovered from live or necropsied, *Chlamydia*-negative trauma cases, koalas with clinical signs but with disease free semen or koala semen which tests positive for *Chlamydia* but which could be subsequently cleaned up with antibiotic therapy. Such semen could be stored in a frozen bank or be inseminated directly after short-term chilled preservation into females. As a side note, we have recently reported *Chlamydia* related orchitis in two out of 18 koalas with clinical signs of the disease (Dief, 2012); these infections appeared to have resulted in degeneration of the seminiferous epithelium. It is, therefore, likely that *Chlamydia*-induced infertility in male koalas may be more of an issue than first thought. We believe it is therefore important that semen and reproductive tissue coming into the koala hospitals be routinely screened for chlamydia. Interestingly, the epididymis of the remaining 16 animals showed no evidence of the organism and could potentially represent a source of valuable genetic material to be recovered and used for artificial breeding.

Genetic propagation

We propose the establishment of a koala breeding centre that could be used for the production of genetically scripted koalas for release into either reclaimed or restored habitat. The captive breeding concept has been well utilised in other endangered marsupials and perhaps it is now time to consider such an approach in the koala. The same centre could also be used for a range of studies of koala biology.

Koala breeding centre

The establishment of koala breeding centre could allow for the careful genetic management of captive populations that could be used for restocking rehabilitated or reclaimed empty habitat. Perhaps such a centre could be managed by a collective of government, universities and zoos, the latter of which could provide significant resources in terms of captive husbandry. Such ideas are perhaps a little controversial but surely it is now time to start considering new ways of thinking in what appears to be a koala crisis, at least in south east Queensland. Perhaps koalas in the central coast region could be used to pilot some of these concepts. There are also opportunities for similar concepts on some of the island koala populations off Queensland but these ideas will need to be carefully considered.

Conclusion

In parallel with studies of koala distribution and models of population growth we believe it is now time to re-focus work at the whole animal level to improve our understanding of fundamental biology and begin to implement strategies that not only safe-guard koala populations but aim to increase them, both in terms of their actual numbers and genetic integrity. We would strongly encourage government, and the scientific community more generally, to consider and acknowledge the importance of whole animal science and the use of captive animals as part of the bigger solution to koala conservation and to fund this type of research more generously. In other Australian states there appears to be a good working relationship between government and zoos for cooperative research and conservation education; it is time this relationship is repaired in Queensland.

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WORKSHOP SESSION 3: Captive management in global koala conservation (local, national and international refuges for koala genotypes)

This workshop session followed presentations which highlighted the importance of captive koalas to understanding fundamental biology and the role of zoos and wildlife parks in koala conservation. The need to use physiological and behaviour data from captive koalas to inform models of population biology and disease epidemiology was rigorously reinforced. This workshop essentially sought to emphasise that captive koalas have more than just an educative role in conservation, in that they can potentially be used more directly for genetic management and research.

During this workshop, the establishment of an Australian Koala Research Centre was proposed, and conceptualised as a multimodal interaction model whereby there is envisaged to be a number of functional nodes associated with key areas of research, for example: disease, ecology and physiology. Zoos could play a major role across a number of these nodes, including the provision of veterinary hospitals (e.g. Currumbin Wildlife Sanctuary and Australia Zoo) and the understanding of basic biology (e.g. Dreamworld). Zoos would not only provide access to their husbandry and breeding expertise but also to captive populations of koalas that might serve as genetic reservoirs (live genome banks) of locally threatened populations.

A view was expressed that zoos and wildlife parks should aim wherever possible to have koala populations that were representative of their local populations; perhaps these koalas might even be kept off exhibit. Given that these animals could potentially be genetically characterised, they could then be carefully managed to maintain or improve existing heterozygosity. They could also be used to facilitate genetic exchange in order to span isolated fragments of habitat, capture genetics of animals destined for translocation or recover genetics from koalas that die prematurely due to misadventure or disease. It should be noted that breeding techniques for the purposes of koala genetic management could either occur naturally or by artificial insemination. The successful development of artificial insemination in the koala has so far produced 32 pouch young and allows shipment of semen rather than whole animals. Artificial insemination could allow semen to be collected from wild males in the field, the males released and the semen inseminated across isolated fragments and into females that are kept for short periods of time in captivity and then subsequently released (with pouch young) back into the wild. The development of artificial insemination with frozen-thawed semen would further enhance genetic management through time, as koala spermatozoa could be managed long after (up to 50 years) the normal generation interval of the male. Once cryopreservation technology of koala spermatozoa has been successfully developed, it is possible that the Australian Koala Research Centre could be the curator of a Queensland wide frozen genome bank in which selected males from all wild koala populations could be represented. It is also possible that with appropriately implemented safe guards, national (intra- and interstate) and international zoos could help manage and store back up frozen genome bank facilities to reduce the risks associated with cryostorage failure.

The development of an Australian Koala Research Centre could also facilitate genetically managed breeding programs for the reintroduction of koalas into rehabilitated habitat, where natural reestablishment of koala populations was not possible. The selection of such animals needs to be based on the genetics and pre-adaptions of existing surrounding local populations. The koala research centre might involve the establishment of semi-captive enclosures that would allow for the observation of more natural behaviour and physiological ecology. Such a facility would also allow researchers to explore and test structures designed to reduce koala anthropogenic mortality. This type of facility would allow a better understanding of the ecophysiological tolerances of koalas to climate change and to adverse whether events. It is possible that these koalas could be sourced as rehabilitated animals from koala hospitals or as animals that would normally be regarded as non-releasable.

Semi-isolated populations such as those on islands may no longer naturally regenerate and there might be an opportunity to use zoo expertise to preserve genetic material of these populations by removing some individuals for reestablishment. There are also koalas on Queensland islands that may have representative genetics from locally extinct mainland populations – these mainland populations could potentially be re-constituted by island genetics. Such a scenario could only occur after close genetic scrutiny and analysis.

The primary task resulting from the workshop was to “work towards the establishment of an Australian Koala Research Centre”.

Theme 4. DISEASE AND KOALA ECOLOGY

Disease and ecology in central Queensland

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Introduction

Most research into the impacts of diseases on koalas takes place in wildlife hospitals in and near Brisbane, but there is a great deal to be learnt about the relationship between this disease and its host across its range, most of which in Queensland is outside of the south east corner of the state. The non-urban yet heavily fragmented resource extraction region of central Queensland provides a useful comparison to the undisturbed St Bees Island population – and both of these groups have been the subject of research for many years.

The impact of disease in non-urban populations of koalas is not really well known. Rates of infection, the relative impact of the different strains of *Chlamydia* and the prevalence and impact of koala retroviral infections remain unexplored, yet these issues are approached on the basis that what applies in the south east of the state will also apply in central Queensland.

What is the situation with koalas and disease in central Queensland? The following points need to be addressed:

- Exactly what constitutes disease, what causes it and how is disease spread?
- Are there any spatial correlates to pathogenicity or immunity? Do rates of subclinical infection vary across the range of the koala and what patterns exists and what are the long-term consequences for infected koalas in different areas?
- What is the potential for natural immunity to exist, to be maintained and even to be conveyed between populations? Is natural immunity localised or widespread? Does it vary with individuals or populations?
- What is the impact of stress – does it mediate immune responses or play a role in disease expression?
- What role does the koala retrovirus play in disease outcomes for koalas – with particular respect to Chlamydia?

Despite a series of taxonomic changes over the last 20 years, it appears that *C. pecorum* and *C. pneumoniae* are the infectious agents of this disease for koalas, which poses the question as to why the disease is not highly zoonotic in the case of *C. pneumoniae*. In 1999 Girjes et al. found a remarkable sequence relatedness between one of the koala strains of

Chlamydia and *C. pneumoniae*, but did not conclude them to be one and the same. Over the last 20 years we have had to change our text to reflect the latest name for the disease, but throughout it's been clear that there are two strains of koala *Chlamydia*, so maybe the old terminology (Strain 1 and Strain 2) was the best approach.

Exactly what constitutes disease, what causes it and how is disease spread?

Chlamydia is thought to be a major cause of mortality in south east Queensland, but is this also the case in central Queensland? Should investigations of disease be a priority outside of the urban areas of the state, or could such research even inform management within those areas?

Better knowledge of the breeding system of koalas would aid an understanding of a disease that is sexually transmitted, yet there are already models that describe the efficacy of population-level control measures for *Chlamydia* that have been developed in a vacuum of such information (Rhodes et al., 2011). The various modes of transmission need to be investigated before such models or methods are taken too seriously. Indeed, infection rates with *Chlamydia* appear to vary significantly across the state, as do the disease signs and the severity of impacts on the populations (Figure 1).

There is discussion about what constitutes a diseased koala, because in the south east of the state, it appears that up to 40% of observably healthy koalas will be found, upon in-depth veterinary examination, to harbour infection. In some cases these animals will be found to be infertile. The view of the predominant vet is that for some areas of south east Queensland, some 30% of all koalas observed free of infection will develop infection over time (J. Hanger pers. comm.), so our approach to this disease needs to be better informed, with a broader approach that includes expertise from south east Queensland with experience from central Queensland.

Figure 1 shows the proportion of *Chlamydia* polymerase chain reaction (PCR) positive swabs of koalas on St Bees Island and the proportional fecundity of females. For a disease that causes infertility you'd expect to see a different relationship between the rate of infection and level of fecundity. These animals are infected by *Chlamydia* but they exist as a stable, healthy, breeding population of koalas. This leads us to wonder if the animals have levels of natural immunity and can naturally respond to infection with *Chlamydia*. Alternatively, is the strain of the disease on St Bees Island less aggressive than at other locations? There are groups of animals like the St Bees animals in other parts of the koala's range, so perhaps there are more examples from which we can investigate tolerance or resistance in koalas. Once a koala comes in contact with *Chlamydia* it becomes seropositive (these animals produce *Chlamydia* specific antibodies), and by using an antibody-specific blood test we are able to determine what proportion of koalas have encountered the disease without developing disease signs. Because there seem to be many koalas in various locations that are seropositive but aren't showing signs of infection, we presume that these koalas must have a natural immunity or tolerance, but perhaps at various locations the strains of *Chlamydia* are less pathogenic.

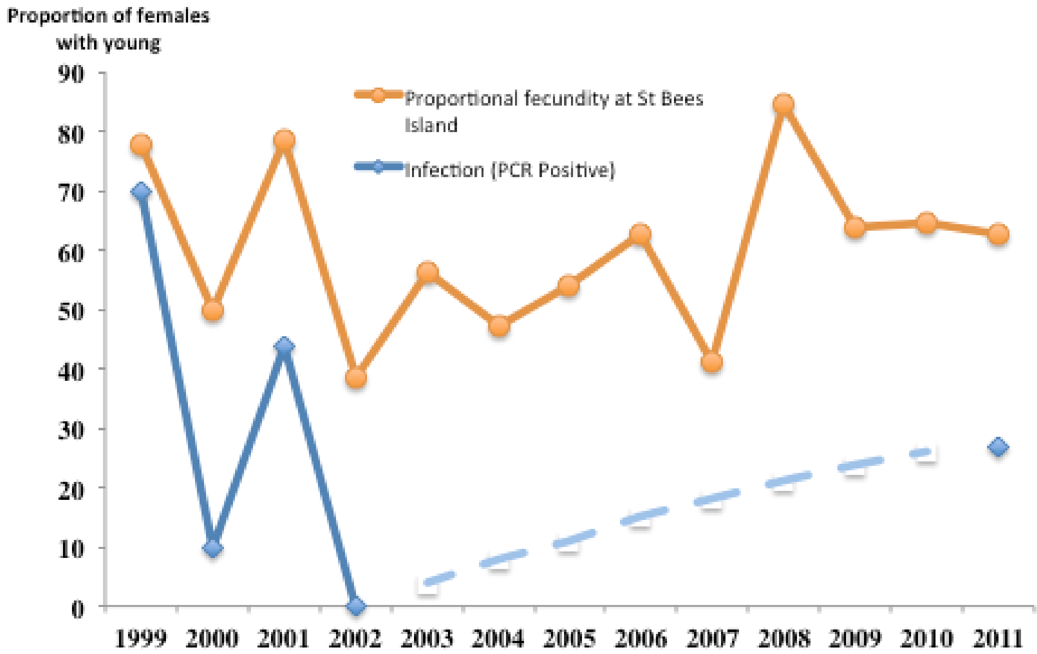

Figure 1 Proportional fecundity and infection with *Chlamydia* at St Bees Island.

Are there any spatial correlates to pathogenicity or immunity? Do rates of subclinical infection vary across the range of the koala and what patterns exists and what are the long-term consequences for infected koalas in different areas?

The proportion of koalas with disease doesn't mirror the proportion showing infection in central Queensland. Sub-clinical (non-overt) infection is common; we rarely find infected eyes and other standard symptoms that are commonly observed in south east Queensland. In central Queensland we see high infection rates with low disease expression (Table 1, Figure 2). During our 2011 survey, 36% of St Bees koalas were PCR positive for *Chlamydia* but only 7% showed visible signs of infection. This is a vastly different situation to south east Queensland, although quite similar to what we see on North Stradbroke Island and in central Queensland. What is it about St Bees Island that might be different to the mainland of south east Queensland, or is the situation that we see normal and the heavily disturbed southeast Queensland population the aberration? Could a priority be to quarantine St Bees Island to ensure that if a pathogenic strain of *Chlamydia* is not there now, one is not bought over during animal care programs or research work?

Table 1 Infection and expression of *Chlamydia* in various koala populations.

Location	Overt signs + ve	$IBDT_2$ + ve	CF test + ve	PCR + ve	Plasma Cortisol nmol l^{-1}(Std dev)
Blair Athol	7%	N.D.	N.D.	7%	15.98 (3.9)
Hospital	90%	50%	30%	N.D.	13.76 (4.6)
St Bees	7%			36%	
Redlands				64%	
Stradbroke Is	0%			80%	
Springsure	7%	33%	20%	33%	19.75 (6.1)
Captive	22%	44%	11%	45%	13.27 (1.9)

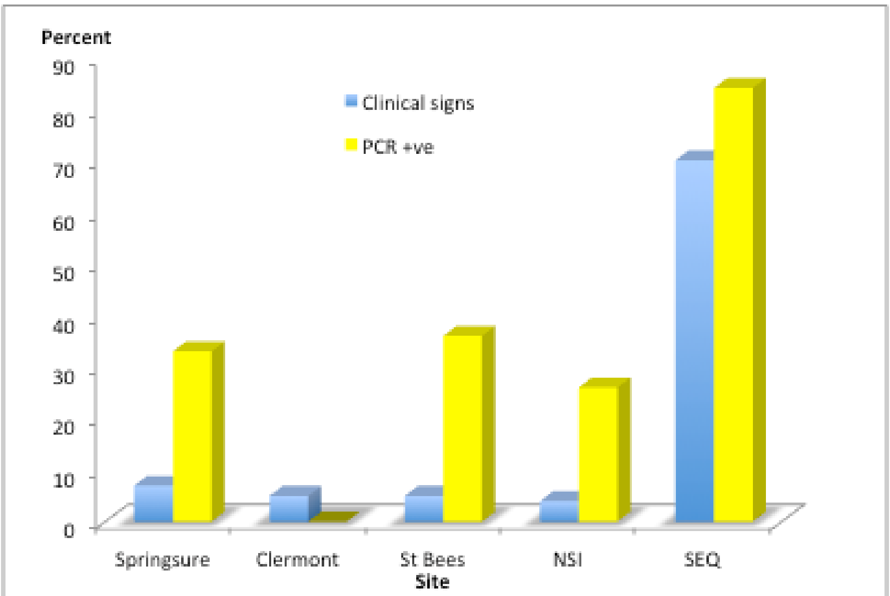

Figure 2 High rates of chlamydial infection (PCR +ve) with low rates of expression (clinical signs) in central Queensland koala populations.

What is the potential for natural immunity to exist, to be maintained and even to be conveyed between populations? Is natural immunity localised or widespread? Does it vary with individuals or populations?

The idea that koalas can produce antibodies that will neutralise chlamydial infection is not new. A 1993 study showed that koalas could produce neutralising antibodies to chlamydial infection (Girjes et al., 1993). In recent research, however, this finding seems to have been forgotten (Carey et al., 2010) and there is no acknowledgement of the fact that koalas appear to be able to mount an effective immune response to *Chlamydia*, or that this has been described previously. With this apparent anomaly existing, some current research has been directed toward a vaccine for chlamydial infection in koalas, but nothing is directed toward understanding the way koalas may deal with such infections naturally. This could be harmful to the long term conservation of koalas for several reasons:

1) Natural immunity or tolerance to chlamydial infection is likely to be maintained in populations because those animals that harbour such immunity or tolerance are at a selective advantage. Koalas unable to mount any defence or unable to tolerate chlamydial infection will be less likely to reproduce, compared to their better-equipped conspecifics. The naturally healthy, yet infected, populations that we see may reflect a selection pressure of chlamydial infection in the population, resulting in more tolerant or resistant individuals. Provision of a vaccine, if effective, would remove the selective advantage naturally immune or tolerant koalas currently have, so in the long term the population will be characterised by a lower proportion of naturally immune or resistant individuals. Under this scenario, which appears very real at our sites, vaccines provided to populations that currently harbour a sufficient immune capacity would reduce the overall fitness of the population in the face of disease;

2) Although strong arguments are being mounted for the development of a vaccine as a treatment method for koalas bought into care in southeast Queensland (and certainly the carers trying to nurse these animals back to health need all the tools they can get) there is no compelling argument for such a course of action in free ranging populations in central Queensland. There is, however, the potential effect of any undiscovered side-effects that could have catastrophic long term impacts at a population level. The risk of introducing an infectious agent or impacting reproductive or other behaviour should outweigh the potential benefits (currently none) of introducing a vaccine;

3) The allocation of resources into such a venture as a vaccine, particularly beyond the carer environment in south east Queensland would mean resources would be removed from other, worthwhile areas of research and management, such as identifying genetic links to tolerance or disease resistance, or the role of strain pathogenicity in mediating disease outcomes for koalas;

4) Currently there is no evidence that the vaccine approved for field trials in south east Queensland engenders any positive disease outcomes for treated koalas nor that it protects from infection or reduces the opportunity for transmission of disease. What is known is that if effective a vaccine would need to be administered to every koala, possibly every year.

What is the impact of stress – does it mediate immune responses or play a role in disease expression?

Physiological stress can potentially impact on the immune status of koalas – can we measure stress and its impact on disease in koalas?

Are low circulating stress hormone profiles associated with better defence against infectious disease in koalas?

Is cortisol a good measure of the stress status of the koala?

Can we measure it?

- Is it produced in response to stress?
- When and how does it appear?
- Is it a useful measure?

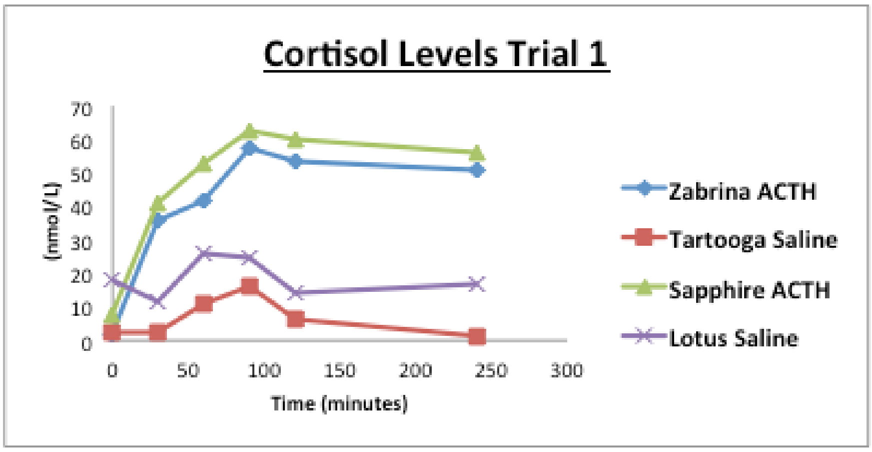

Figure 3 Cortisol in the blood of koalas challenged with ACTH agonist (Synacten) or a saline placebo.

Koalas that have been challenged with adrenocorticotrophic hormone (ACTH) do produce higher levels of cortisol in the blood and have a relatively repeatable response (Figure 3). This indicates that there is a link between stressful events and the presence of cortisol in the blood of koalas.

Preliminary data suggests it is also possible to measure cortisol in faecal samples (Figure 4).

The presence of cortisol in the faeces of koalas treated with an ACTH agonist indicates that there is a potential to use the non-invasive method of scat collection to measure stress hormone profiles of koalas in the field. This could enable us to detect stressful events and investigate their links to disease outcomes for groups of koalas.

But when looking at an animal that has been admitted to hospital after trauma, the response is non-uniform and unclear, the acute stress event may mask the chronic measurement (Figures 5 and 6).

In the wild situation, when we compare plasma cortisol levels to sick populations in hospital we don't see a significant difference. There doesn't seem to be a pattern to suggest there are higher levels of circulating stress hormones in the blood of sicker koalas (Table 1).

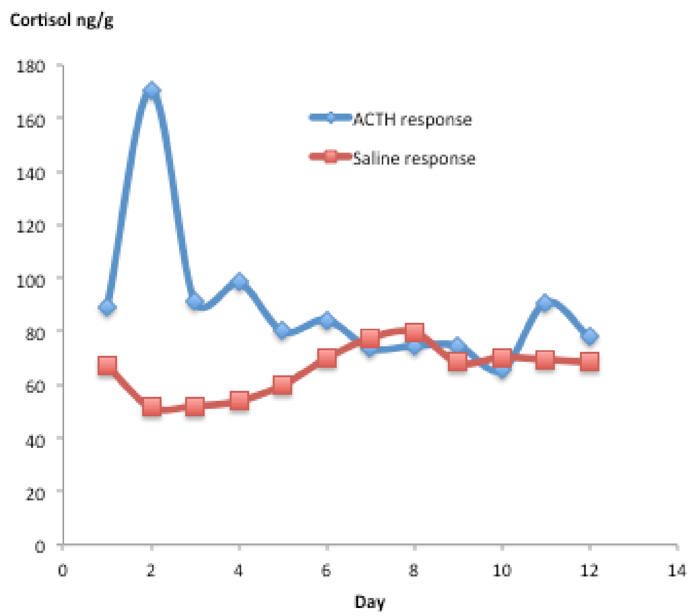

Figure 4 Appearance of free cortisol in the faeces of koalas after challenge with ACTH or saline placebo.

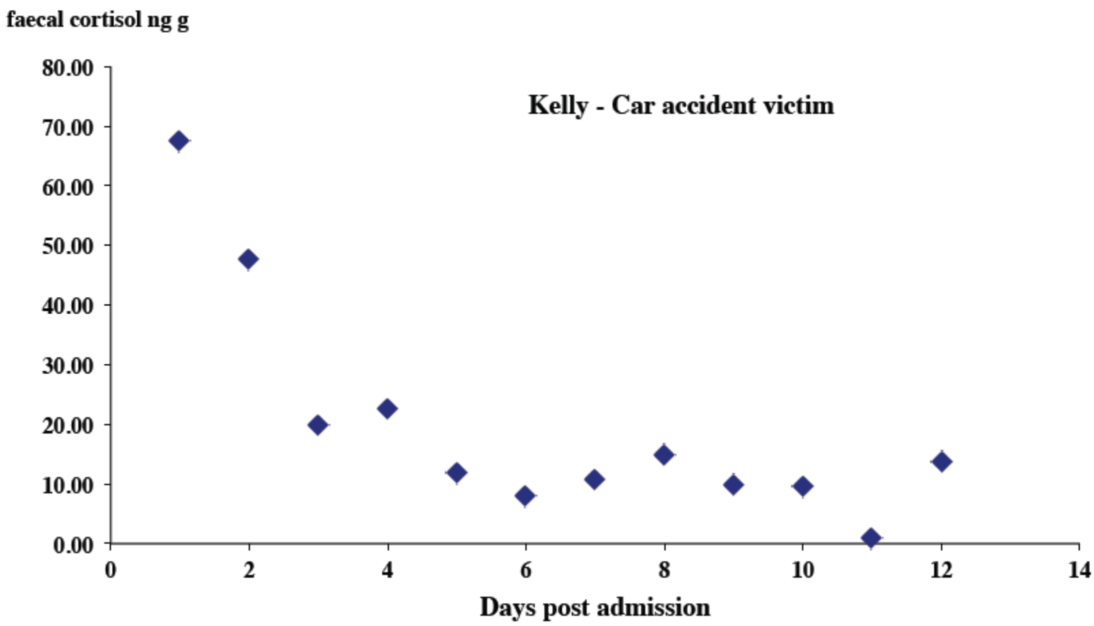

Figure 5 Faecal cortisol in a koala admitted to hospital following trauma.

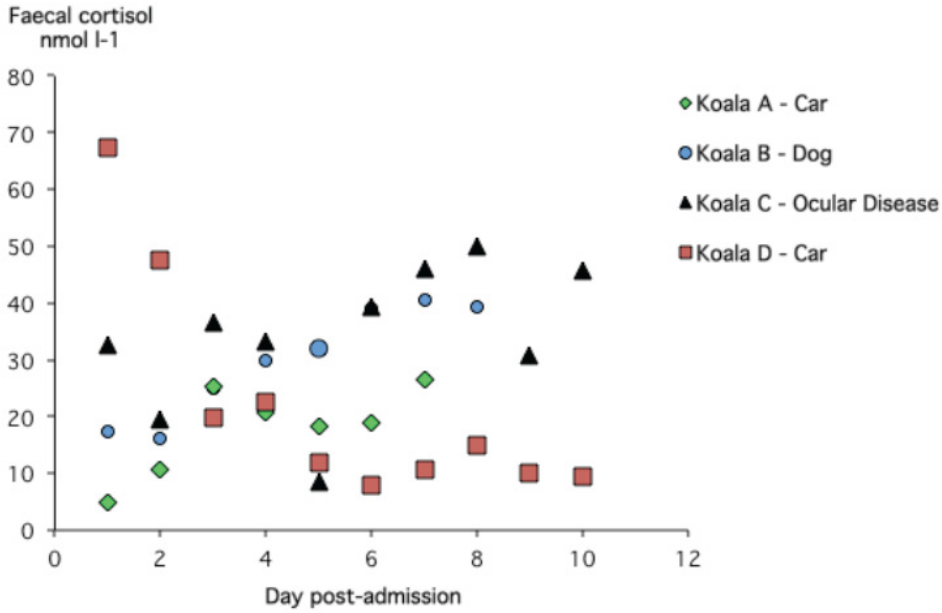

Figure 6 Post-admission faecal cortisol in koalas admitted to hospital.

What role does the koala retrovirus play in disease outcomes for koalas – with particular respect to *Chlamydia*?

Could Koala Retrovirus (KoRV) be the answer? It doesn't seem like this is the case because all the koala populations here are showing virtually 100% KoRV infection and yet they are healthy (Figure 7).

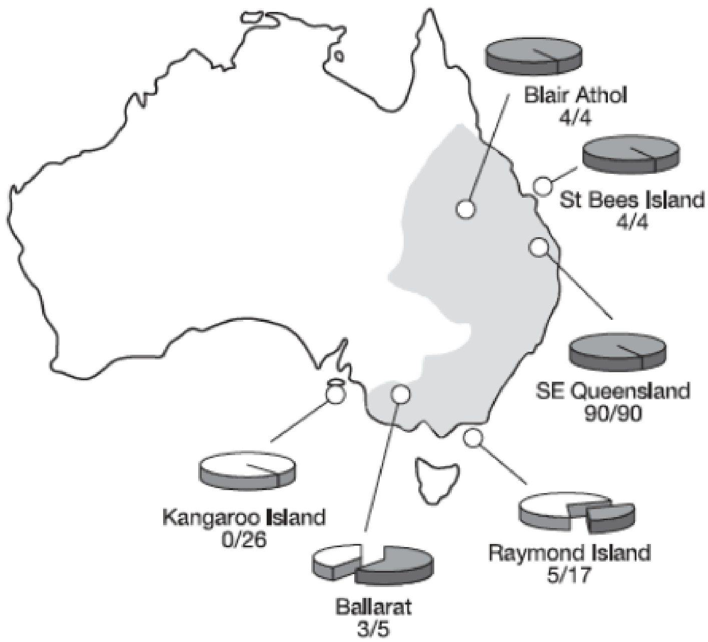

Figure 7 Koala Retrovirus infection rates (Tarlinton et al., 2006).

Take home messages

- *Chlamydia* and KoRV are endemic to populations of koalas in Queensland.
- Disease is not the primary cause for concern among many of these populations – most are healthy.
- Koalas appear to possess some immune protection or tolerance to/against *Chlamydia*: understanding this is probably the key to assisting those populations that have serious problems (i.e. Koala Coast).
- There are significant ecological considerations that need to be considered before we start wholesale treatment of koala populations with vaccines. The situation in south east Queensland may need to be approached in a different manner to the bulk of the state.
- Differences in immune protection or disease pathogenicity could explain the variable impact of *Chlamydia* for koalas. Physiological stress is less likely, but there is research in this area.

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Zoo based conservation: collection-driven koala health research

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We have considered how zoo-based koala populations can inform field problems. In this paper we consider how animals in the field assist the management of captive koala populations. San Diego Zoo has a long history of managing captive koalas and facilitating research on these animals (Table 1).

Table 1. Short history of koala management and research at San Diego Zoo.

1925	3 koalas
1950's – 1970's	exhibit koalas
1976 onwards	major effort with multiple imports
1983	San Diego Zoo Koala Education and Conservation Program
	Loan money supports koala research
	Behavioural Biology
	Collection-driven research
1990's	Retrovirus research [*Note: including field expedition with Dr Melzer at Springsure Eds*]
Contemporary San Diego Zoo Supported Research	Koala Reproductive and Population Ecology Study, Dr William Ellis
	Gamete Recovery from Chlamydia Infected Koalas, Dr Steve Johnston
	Genetic Marker, Vit D, MHC, SPEP Sample Collection, Dr Geoff Pye

Koala Retrovirus

As zoo veterinarians, our work tends to be driven clinically by the disorders and diseases we see in our collection. In the 1990s, we looked at Koala Retrovirus (KoRV) (Table 1), and in 1993 presented the results at the annual conference of the American Association of Zoo Veterinarians: the studies showed a high incidence of malignancies, leukaemia, osteosarcoma, and osteochondromatosis (bony tumours of skull), as well as opportunistic infections resulting from immune system suppression by KoRV.

Last year, an updated mortality report of the San Diego Zoo (SDZ) koala population from 1925-2011 showed that 30% of deaths were directly related to KoRV (e.g. lymphosarcoma, leukaemia, bone marrow hypoplasia, anemia). Probably an additional 10% of deaths were associated with opportunistic infections (e.g. cryptococcosis). In total about 40% of koala deaths at SDZ have been associated with retrovirus.

Dysplasia

Dysplasia (abnormal joint formation) was noted in the hips of koalas at SDZ. Was it a genetic problem or a nutritional problem? In 2005-2006, a retrospective and prospective study of the SDZ koala population for hip dysplasia revealed 55 cases (Figure 1). Soon after the survey was published (2008) a female koala presented with an issue with her right arm that revealed that she had shoulder dysplasia (Figure 2). So a retrospective and prospective survey for shoulder dysplasia was run the SDZ koala population and 43 cases were found. Dysplasia was found to be limited to only the shoulder and hip joints and a correlation between severity of shoulder and hip dysplasia was identified (a severe case of hip dysplasia meant there was a 92% chance of severe case of shoulder dysplasia). However the research still didn't show if the problem was genetic or nutritional.

At the time, we didn't know how koala hips formed. Subsequently the next joey born was radiographed every month from pouch emergence to 28 months of age. This did not reveal normal hip development, but we did see how hip dysplasia developed in this joey. The initial radiographs were also suggestive of metabolic bone disease (Figure 3). All the female koalas at the zoo were then shifted outside for breeding, gestation and raising their young. The consequence was an immediate elimination of metabolic bone disease and a decrease in observed dysplasia severity.

Joeys that died at young ages in other facilities showed signs consistent with metabolic bone disease, likely due to lack of vitamin D from no solar exposure. It is difficult for zoos in cold climates to house koalas outside (limited space means there can't be both indoor and outdoor enclosures), so koalas are held inside all year round. There is a significant correlation between indoor housing and the incidence of metabolic bone disease. We are now recommending that koalas are housed outside whenever possible. Provision of UV lights and/or vitamin D supplementation should be considered when this is not possible in the colder months.

SDZ currently has no "normal" koalas: 95% of population are affected by dysplasia and the small proportion that aren't have produced joeys that are affected. Consequently we needed a normal phenotype for genetic comparison testing, so we looked for a wild population. To do this we piggybacked onto William Ellis's work at St Bees Island. We radiographed the hips of wild koalas to prove their normal phenotype and we collected DNA samples for genetic testing and blood (serum) to measure the "normal" vitamin D levels for koalas that have access to sunlight all day. Knowing normal levels can help determine the supplementation rate of vitamin D or UV light required for koalas in captivity. Serum was also used to develop normal values for protein electrophoresis, a diagnostic tool that can aid in the diagnosis of disease. We also collected scent gland secretions / MHC genes, and DNA samples for the Frozen Zoo®.

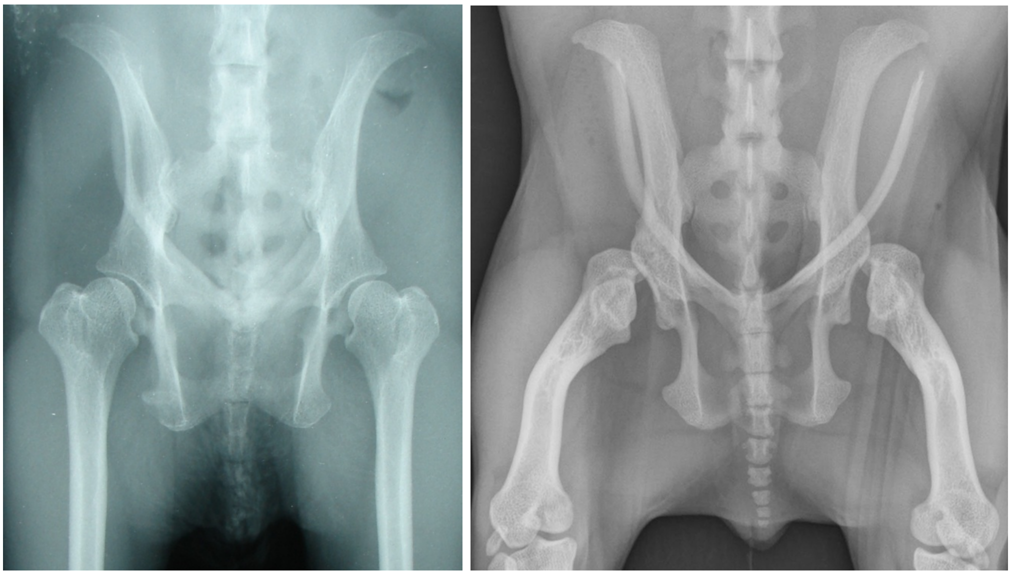

Figure 1 Normal koala hips (left) and hip dysplasia (right).

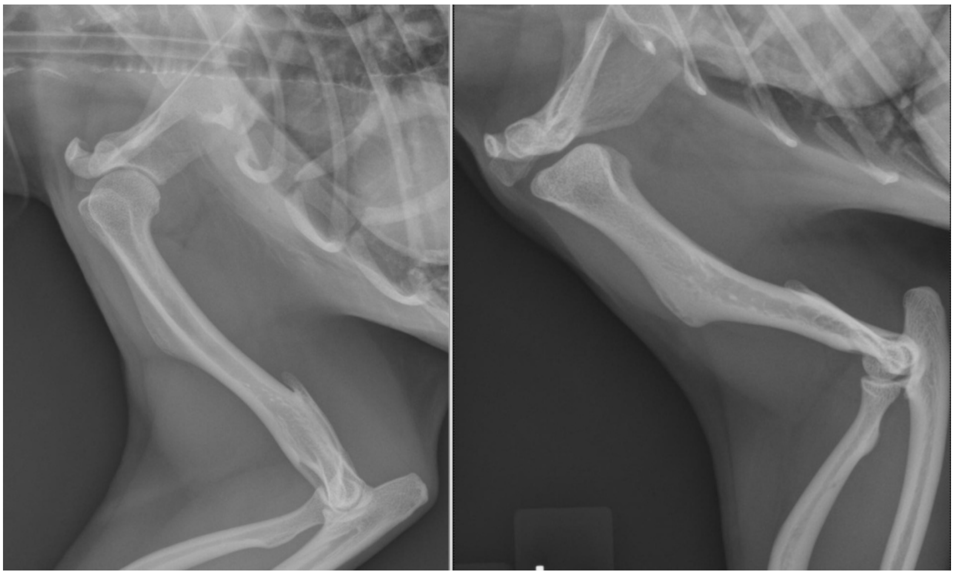

Figure 2 Normal koala shoulder (left) and shoulder dysplasia (right).

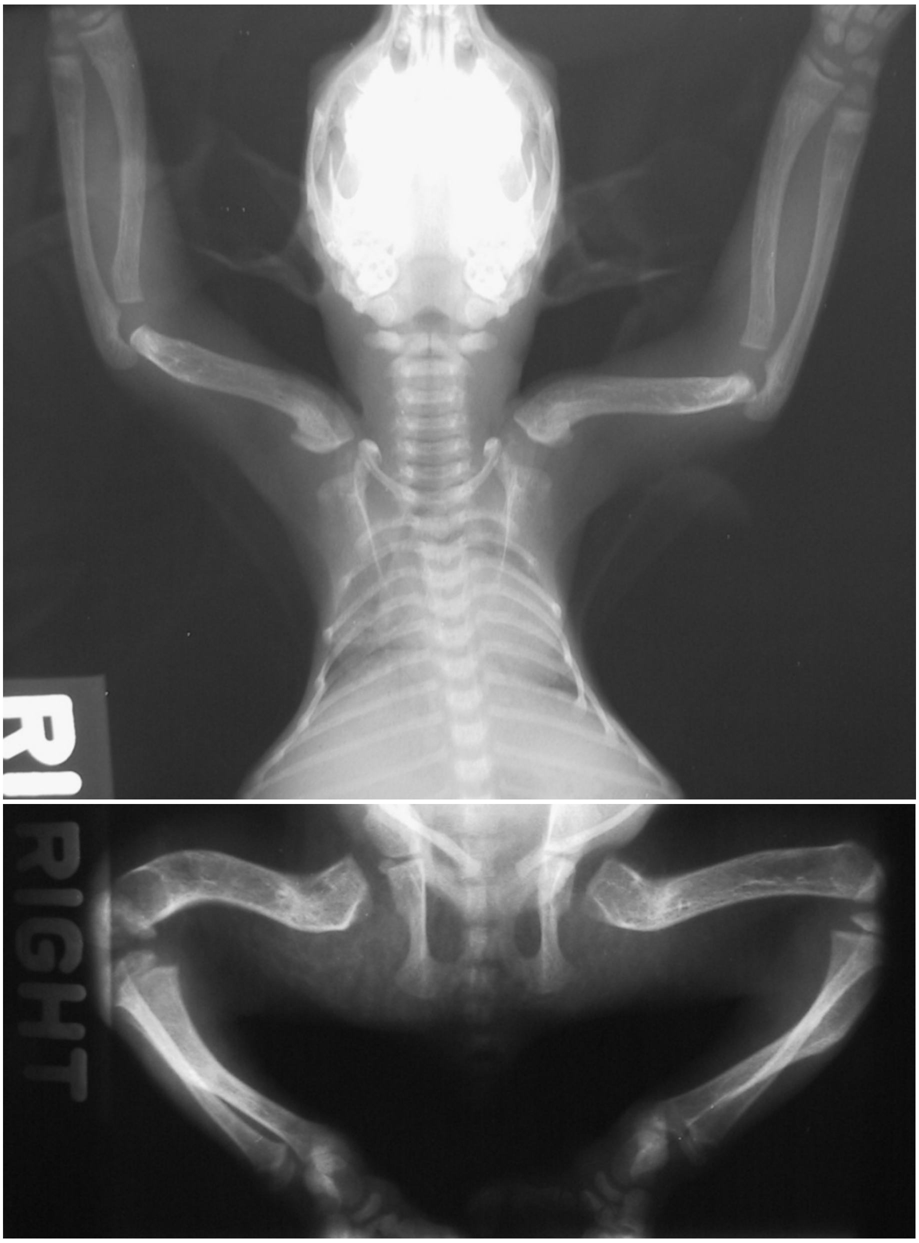

Figure 3 Metabolic bone disease and hip dysplasia in a koala joey.

In the past radiographic field work would have required heavy equipment and a generator, but now it is possible to use a battery powered x-ray unit with a digital film that less than 2 mm thick. We could hike the mountains of St Bees with this equipment and were able to determine that the hips were normal and that bone composition was normal as well.

Results of the vitamin D study showed that healthy, free-ranging koalas have comparatively low serum vitamin D levels naturally, which reinforced findings presented in an abstract from the Wildlife Disease Association – Australasian Section conference in the early 1990s that showed a number of marsupial species have quite low serum vitamin D levels. This means supplementation is easier but it also increases the potential for overdose toxicity, particularly when supplementing with vitamin D rather than providing artificial UV light.

The electrophoresis work was published and follow up work will be to correlate necropsy results with the data bank at the zoo. The Frozen Zoo® is an international wildlife gene bank. It banks tissues (cells, tissues, blood, DNA and gametes), and, amongst other things, has produced a koala cell line which is available to researchers.

Koala Retrovirus

Current KoRV research has been carried out in collaboration with the National Institute of Health (NIH), the Centre for Disease Control (CDC), the University of Illinois, and the Leibniz Institute for Zoo and Wildlife Research. There is a process at the SDZ where researchers can ask for biomaterials and animal data and this is opportunistically collected during preventive medicine examinations.

A second KoRV has been identified by researchers at NIH and CDC (the original is KoRV-A and the new one is KoRV-B) and this second KoRV has been fully sequenced. The receptors are different to the original KoRV. It is yet to be determined whether KoRV-B is an endogenous virus. The implications of this discovery have opened more questions than answers about KoRV. It would be useful to consider the importance of KoRV in free-ranging versus zoo-based koalas.

The data is also exciting for potentially answering questions about human retrovirus – the research is not focussed solely on koalas. The supposition about retrovirus is that it was a new virus infecting the koala population within the last two centuries, but there may be evidence that the virus was present prior to white settlement.

Nasal mass removal

Another article to be published soon details nasal mass removal in koalas – surgical removal is not well described so the successful removal of masses from nasal passages was documented alongside normal skulls (gross anatomy and computed tomography [CT] images).

San Diego Zoo Conservation Programs

The San Diego Zoo Global Conservation Programs are supported largely by philanthropic donations. Together they form the largest zoo-based multidisciplinary research effort in the world, involving 150 scientists in 38 countries, who are working with 172 species. There have been 25 reintroduction programs and 243 conservation partnerships.
www.sandiegozooglobal.org

Landscape change and disease in Queensland koalas

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Introduction

Mortality from disease has been shown to be a crucial factor affecting wildlife species' viability and dynamics (Bairagi et al., 2007, Packer et al., 2003, Su et al., 2009). Furthermore, habitat disturbance is increasingly recognised as a vital factor that impacts on the health and fitness of the animals in habitat fragments (Cottontail et al., 2009). In general, the loss and fragmentation of habitat causes a reduction in connectivity which in turn leads to critically low population sizes, with lower genetic diversity and inbreeding depression, making them more susceptible to diseases and stochastic environmental events (Clark et al., 2011). These land use changes can alter ecological and evolutionary processes, including those between hosts and parasites (Chasar et al., 2009, Walsh et al., 1993). Ultimately, the importance of disease for the conservation of species threatened with habitat loss will increase with decreasing habitat size and quality (Smith et al., 2009). The serious threat of disease epidemics in wildlife means that monitoring the prevalence of disease should be a priority in conservation (Scott, 1988).

To gain a better understanding of the influence of modified landscapes on disease it is important to explore potential mechanisms involved in driving variations in disease prevalence. Furthermore, if disease-driven declines in population sizes and local densities are added to the higher mortality rates arising from multiple-sources in modified landscapes, this will increase the threat to the long-term viability of a species (Rhodes et al., 2011). Therefore, understanding the influence of habitat modification on disease prevalence is important for ensuring species survival in landscapes that already experience increased mortality rates from multiple threats.

This problem is particularly important for the koala (*Phascolarctus cinereus*) in eastern Australia. Koalas are folivorous arboreal marsupials restricted to forests containing their primary food source from *Eucalyptus*, *Corymbia* and *Angophora* species (Seabrook et al., 2011). However, although throughout their range they will feed on a range of tree species, they show preferences towards only a few within a particular area (Phillips, 2000). It is now predicted that the current geographic range of the koala is less than half the areas historically occupied prior to European settlement (Sullivan et al., 2003), and this is predicted to be further confounded by changes in climate (Seabrook et al., 2011). While in Queensland, highest densities of the koala are found in southeast Queensland, which is also one of the fastest growing urban areas in Australia (Dique et al., 2004). Therefore, in addition to disease which can cause death and infertility (Hanger and Loader, 2009); threatening processes associated with climate (Gordon et al., 1990, Seabrook et al., 2011) and human-modified landscapes, such as habitat loss and fragmentation (McAlpine et al., 2006a, McAlpine et al., 2006b, Melzer et al., 2000), vehicle impacts (Dique et al., 2004), and dog attacks (Lunney et al., 2007) are also reducing population numbers.

The question addressed in this study was: How does landscape change (e.g. habitat loss, fragmentation and land-use intensity) and climate variability (e.g. rainfall) influence the prevalence and severity of disease (primarily Chlamydiosis) in the koala. We addressed this question using generalised estimating equations models (GEE) to model the influence of temporal and spatial changes to habitat loss and fragmentation, land-use intensity and climate on koala disease prevalence and severity (primarily Chlamydia) in eastern Australia. The data presented are based on 14 years of koala hospital records (1997-2011) collected from ten Local Government Areas throughout the eastern and western portions of southeast Queensland (see below).

Eastern LGAs

- Brisbane City
- Logan City
- Moreton Bay Regional
- Redland Bay
- Ipswich City
- Gold Coast City
- Sunshine Coast Regional

Western LGAs

- Scenic Rim Regional
- Somerset Regional
- Lockyer Valley Regional

Conceptual model and predictions

Figure 1 presents a conceptual model of the spatial and temporal scale landscape and climate factors influencing disease prevalence and severity in Queensland koalas. Embedded in this model is the key hypothesis. The following hypothesis was postulated based on current knowledge of processes threatening koala survival, including habitat loss, habitat fragmentation, land-use intensity and climate variability. See Table 1 for detailed descriptions of explanatory variables.

Hypothesis I. Landscape change and climate variability will cause an increase in koala disease prevalence and severity.

A grid was overlayed onto the study extent, where each grid square represented a landscape that comprised a 10 x 10 km or 10 000 ha area. Grid sizes were selected to account for normal koala dispersal distances of up to 10 km. Explanatory variables and disease prevalence (proportion of disease individuals) and severity (proportion of severe cases) were calculated for each landscape.

We postulate that habitat loss will be the primary process influencing disease prevalence and severity, while habitat fragmentation, land-use intensity and climate variability will have secondary influences.

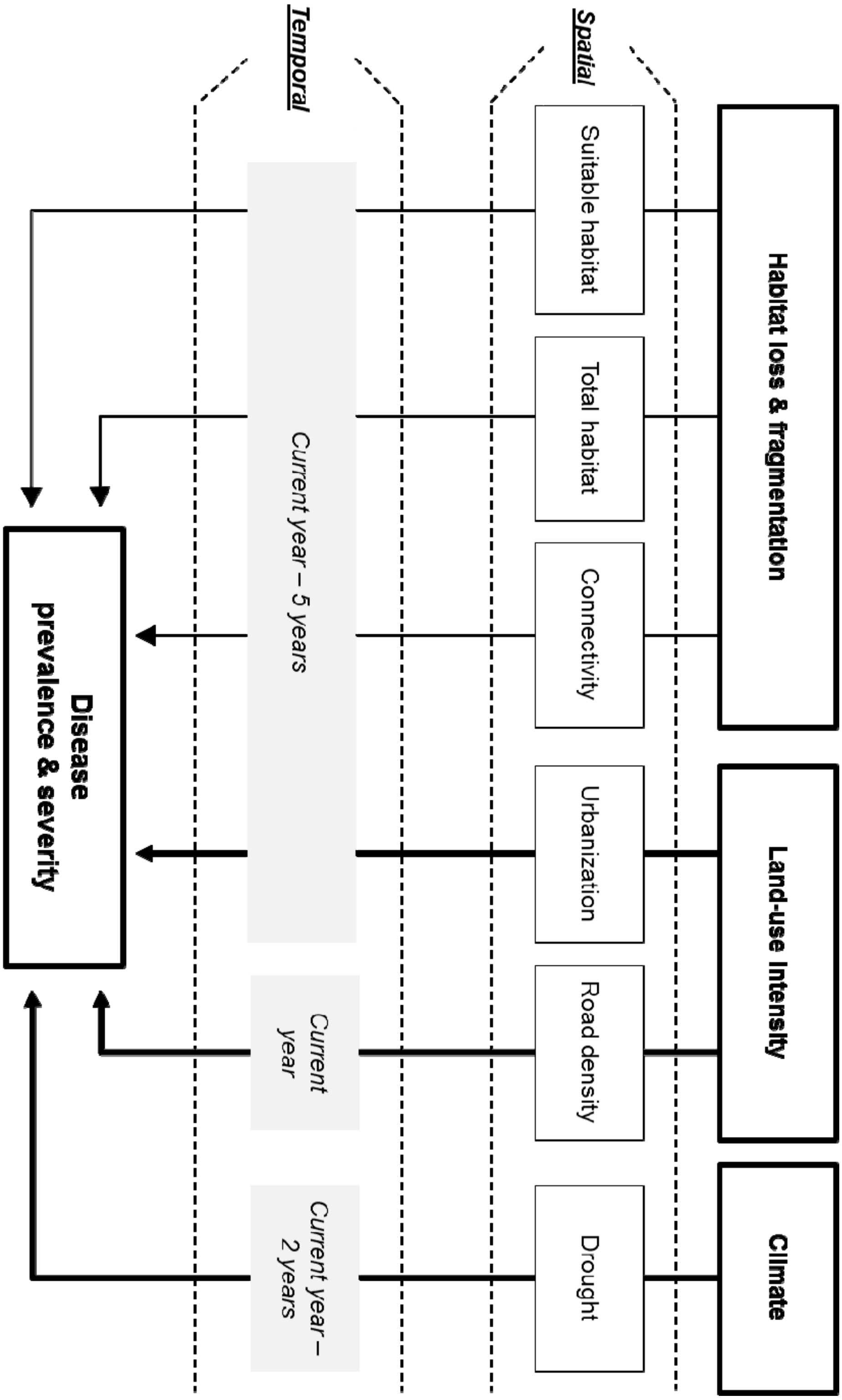

Figure 1 **Conceptual model of spatial and temporal scale landscape and climate factors influencing disease prevalence and severity in Queensland koalas. 'Thick black arrow' indicates a hypothesized positive effect and; 'thin black arrow' indicates a hypothesized negative effect.**

Table 1 Description of landscape change and climate variables used to assess changes in koala disease prevalence and severity within each 100 km^2 landscape (10 000 ha).

Variable	Unit	Time-scale	Full description
Landscape (habitat loss and fragmentation)			
Suitable habitat	Proportion	Current - 5 years	Amount of suitable habitat available in the landscape dominated by primary koala food trees (e.g. *Eucalypt, Corymbia, Melaleuca*)
Total habitat	Proportion	Current - 5 years	Total amount of suitable habitat + movement habitat (e.g. grassland, *Casuarina*, vine/pine forests etc.)
Connectivity	Metric	Current - 5 years	Distance-weighted metric calculated by the distances to nearest suitable habitat patch
Landscape (land-use intensity)			
Road density	Meters	Current	Total length of sealed roads (m)
Urbanization	Proportion	Current - 5 years	Proportion of urban/developed land in the landscape
Climate			
Drought	Millimeters	Current - 2 years	Annual rainfall (mm)

Model results

Disease prevalence

Overall there were some strong effects of the explanatory variables on disease prevalence (Table 2). Five explanatory variable have highly significant influences on disease prevalence ($p <0.001$). Of these, suitable habitat ~ 4 yrs and urbanisation ~ 4 yrs have a positive influence on disease prevalence; while total habitat ~ 5 yrs, urbanisation ~ 2 yrs, and urbanisation ~3 yrs have a negative influence.

Of the remaining explanatory variables, suitable habitat ~ current has a moderately significant negative influence on disease prevalence ($p <0.01$), while suitable habitat ~ 1 yr, total habitat ~ 5 yrs, and drought ~ 2 yrs also have significant influences ($p <0.05$).

Disease severity

Overall there were fewer effects of the explanatory variables on disease severity compared to prevalence (Table 3). Suitable habitat ~ 3 yrs had a highly significant negative influence on disease severity ($p <0.001$). Of the remaining explanatory variables, urbanization ~ 1 yr had a positive influence on disease severity ($p <0.001$), while urbanization ~ 2 yrs and drought ~ current also had significant, but positive influence on disease severity ($p <0.001$). Suitable habitat ~ current was also found to have a weak positive influence on disease severity ($p <0.10$).

Table 2 **Parameter estimate, standard error and p-value of the key explanatory variables identified from the GEE (geeglm) model. Grey shading indicates a positive influence on koala disease prevalence. * = p <0.05; ** = p <0.01; *** = p <0.001.**

Variable	Estimate	Standard Error	p-value
Suitable habitat ~ current	-0.193	0.074	0.009**
Suitable habitat ~ 1 yr	0.145	0.064	0.024*
Suitable habitat ~ 4 yrs	0.180	0.031	<0.001***
Total habitat ~ 4 yrs	-0.186	0.054	0.001***
Total habitat ~ 5 yrs	0.123	0.052	0.018*
Urbanisation ~ 2 yrs	-0.194	0.046	<0.001***
Urbanisation ~ 3 yrs	-0.162	0.047	0.001***
Urbanisation ~ 4 yrs	0.203	0.059	0.001***
Drought ~ 2 years	-0.088	0.041	0.030*

Table 3 **Parameter estimate, standard error and p-value of the key explanatory variables identified from the GEE (geeglm) model. Grey shading indicates a positive influence on koala disease severity. ^ = p<0.10* = p <0.05; ** = p <0.01; *** = p <0.001.**

Variable	Parameter estimate	Standard error	p-value
Suitable habitat ~ current	0.099	0.051	0.051^
Suitable habitat ~ 3 yrs	-0.167	0.047	<0.001***
Urbanization ~ 1 yrs	0.127	0.054	0.018*
Urbanization ~ 2 yrs	-0.162	0.047	0.097^
Drought ~ current	-0.114	0.052	0.027*

Discussion and potential management implications

The results from the model indicate a number of different causal effects on koala disease prevalence. The effects that are identified as key to koala management are discussed below.

The amount of suitable habitat present in a landscape causes an increase in disease prevalence following a one year time-lag. These results are surprising given the importance of key food trees for the koala. However, it is more likely a result of an increased abundance of koalas in these areas, and the subsequent increase in dispersal and sexual contacts. Caution must be taken when interpreting these results and it may be important to further test time-lags that exceed five years to determine whether disease prevalence eventually decreases in these areas. The strong relationship between an increase in suitable habitat and decreased disease severity suggests it is certain that a maximum amount of suitable koala habitat, which maintains higher abundances of this species, far outweighs the effects of disease. The effects of additional anthropogenic threats such as dog attacks and vehicle strikes are also likely to be reduced in these areas. These factors are essential for the long-term persistence of the koala in these areas, because it has previously been suggested that extinctions are likely to only occur if *Chlamydia* transmission rates increase or other non-disease factors change birth or death rates (Augustine, 1998).

Results here suggest that the amount of urbanisation in a landscape will cause an increase in disease prevalence following a four to five year time-lag. It is likely that this time-lag is required to have an effect on koala dispersal rates throughout the landscape, as well as reduce habitat quantity and quality. Initial effects of urbanisation suggest a decrease in prevalence, which may be expected due to the reduced dispersal and consequent sexual contacts. However, following a sufficient time-lag, small habitat fragments that create clumped resources for koalas may be generating a situation whereby there are sexual contacts by low numbers of koalas, without the regular influx of healthy dispersing individuals. Therefore, disease prevalence is elevated. This has implications for koalas in these areas due to the additional population suppressing factors associated with urban areas (e.g. habitat loss and fragmentation, dog attacks, vehicle strikes). It is these areas where koala populations are under serious threat of extinction. To minimise the potential influence of urban landscapes, management must aim to reduce the impacts of other threatening processes by maintaining maximum amounts of connected suitable and movement habitat throughout the landscape to ensure long-term population viability.

An additional causal mechanism that should be considered in urban areas is physiological stress. There are a number of reasons why a direct causal relationship between habitat loss, environmental stressors and disease may exist (see Figure 2 for a conceptual model of the potential link between these three processes). A recent study on squirrel gliders in southeast Queensland showed that individuals living near urban edges (e.g. roads and residential) has considerably higher stress hormone concentrations than those living in forest interiors (Brearley et al., 2012). In addition, the influence of stress on immunity is considered to be the primary pathway through which stress influences infectious disease susceptibility (Cohen and Williamson, 1991). A study on cotton rats (*Sigmodon hispidus*) found that individuals that were treated daily to induce stress had a profoundly lowered ability to resist a viral challenge (McLean, 1982). A recent review of wildlife disease in human-modified landscapes found that no study to-date has directly assessed the landscape change-stress-disease link in wildlife (Brearley et al., in-review).These simple links suggest that the physiological stress of koalas in these habitats should be at least considered when assessing disease risk and prevalence.

Results from the models suggest that rainfall, indicating the presence or absence of drought, has an influence on disease prevalence, albeit only slightly significant. Our results show that increased rainfall (i.e. absence of drought conditions) in a landscape reduced disease prevalence following a two year time-lag. Evidence supporting these results is provide in New South Wales, where koala disease prevalence (i.e. Chlamydiosis) increased considerably following a two year time-lag from reduced rainfall and increased heatwaves. Although both studies are showing opposite trends, they still provide evidence to explore the influence of drought on koala disease. One potential factor is nutritional stress. The effect of drought and heatwaves on the quality of nutrients and moisture available in the koala's diet is now well document (e.g. Gorgon et al., 1988, Gordon, 1990, Moore and Foley, 2000). Links have also long been associated between the nutritional status of the host and both severity and susceptibility to infectious disease. The accepted model proposes that inadequate nutrition impairs the functioning of the immune system, resulting in increased susceptibility to infection. Studies by Beck and Levander (2000) suggest that not only can the nutritional status of the host affect the immune response, but it can also affect the viral pathogen. The strong link between increased suitable habitat and decreased disease severity may be an indication of the importance of nutritional stress in influence disease change. Unlike many arboreal mammals, koalas are unable to escape to nest hollows or find refuge to withstand climate extremes. It is possible that climate extremes combined with the effects of nutritional stress, may result in an increase in physiological stress that will have similar implications to those discussed previously in urban areas.

Conclusion

Results from this study provide the first indication of the effects of landscape change and climate on a wildlife-sexually transmitted disease system. Further, this study indicates the importance of temporal and spatial scale factors of landscape change and climatic variables on koala disease. This was particularly evident in the variability between the effects of landscape and climate factors on disease prevalence and severity following different time-lags. These results follow current knowledge which indicates that influence of human-modified landscapes on wildlife disease prevalence will be variable and typically reflect factors such as host species, transmission type, and disease (Brearley et al., in-review).

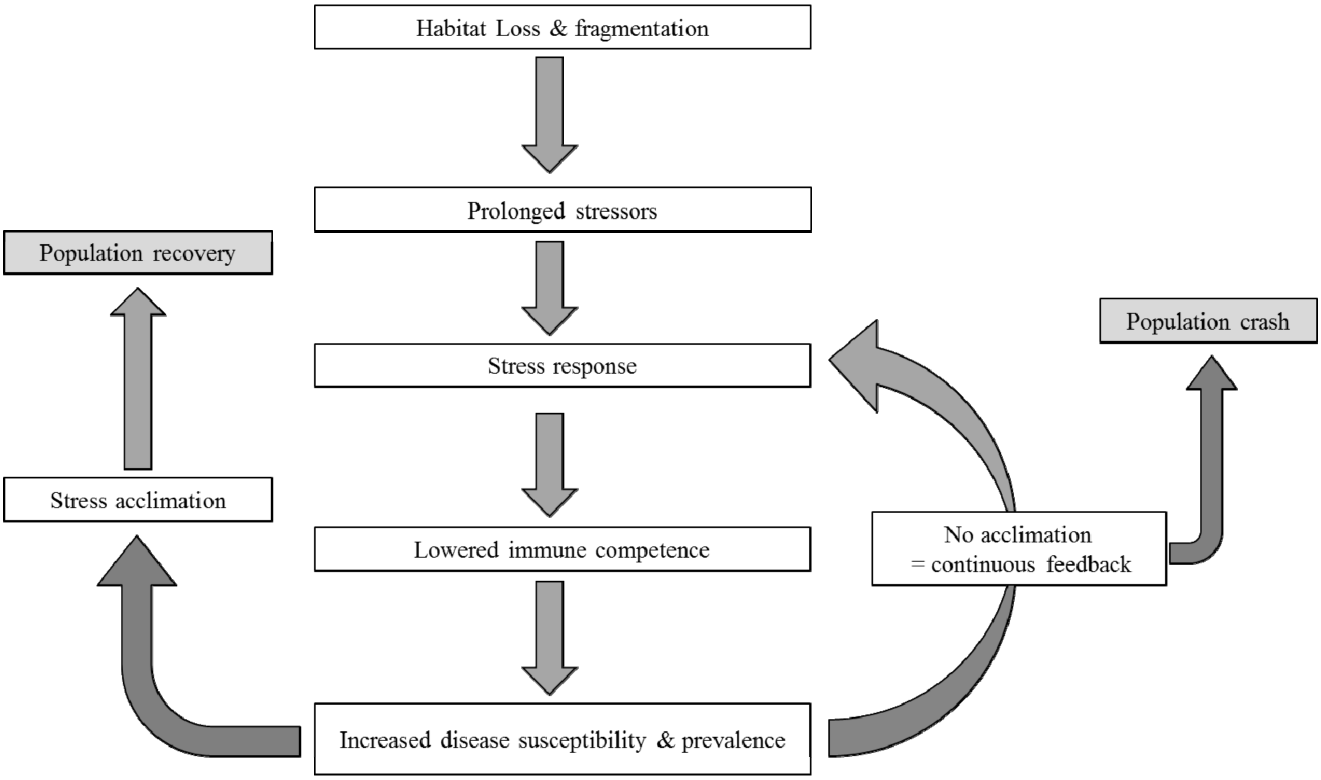

Figure 2 Conceptual model illustrating the processes linking key factors of human-induced landscape change with wildlife physiological stress and disease prevalence for species with different coping abilities.

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WORKSHOP SESSION 4: Role of disease (including koala retrovirus (KoRV) and Chlamydia) in koala ecology and importance for conservation planning

Diseases play a role in koala ecology and their impact varies in different parts of Queensland. Of primary importance in assessing disease risk is the health status of the koala (both the individual and the population), which can be influenced by external stressors (loss of habitat or drought leading to a lack of food trees, overpopulation or overcrowding, human encroachment [vehicles, dogs] etc.) impacting immunocompetence. Immunocompetence can also be affected by koala retrovirus (KoRV) and the combination of KoRV and external stressors may determine the susceptibility to disease. The health of the individual koala versus the population is an important consideration in that individual koalas may be succumbing to disease in an otherwise healthy, stable population. So is the individual koala's status of any importance? It is possible that disease plays a role in the normal ecology of stable koala populations by eliminating the less robust individuals and preventing overpopulation. This is an area where veterinarians and ecologists may clash as their viewpoints on individual versus population may differ and, as a result, the degree of intervention would also differ. It is likely that there is a middle ground where the role of the individual koala in the population could be considered and the degree of intervention to disease is adjusted accordingly. This may be the case in south-east Queensland where rapidly shrinking populations are raising the importance of the individual koala and driving the increased intervention in their individual health.

Chlamydia and KoRV are important infectious and contagious diseases that can have significant effects on free-ranging koala populations. Of lesser importance are *Salmonella*, *Cryptococcus*, and melioidosis (*Burkholderia pseudomallei*). Vehicular and dog attack trauma are not diseases, but they significantly impact koala health. The development of vaccines against *Chlamydia* and KoRV may be useful for captive koalas, but may be unfeasible for wild populations due to the logistics of administration.

So what is koala health? How do we determine when disease is important in a koala population? Is there a cutoff for a proportion of a population affected by disease that is acceptable? What is the significance of *Chlamydia* and KoRV in a stable koala population? What is their role in population control? How do we incorporate public concerns and perceptions about these diseases into management plans for wild koala populations? Where do the answers to these questions lie?

One strategy would be to use sentinel koala sites for intensive disease investigation to determine the role of disease in those sites. Selective surveys could be used to develop benchmarks that could be extrapolated across wider areas. Comparisons between stable healthy populations with little human impact (e.g. St Bees Island) and declining unhealthy populations with extensive human impacts (e.g. areas of south east Queensland) may reveal how diseases and environmental impacts interact together to influence population health and control. It is important to get input from both veterinarians and ecologists, so we can better define koala health and develop guidelines for the assessment of all aspects of population health. The first of these studies will be performed on St Bees Island from September 2012 to May 2013 using disease surveillance, immunocompetence assessment, and proximity collars to measure the potential for disease transmission through interaction and its effects on reproductive success.

In vitro studies have shown that the second novel koala retrovirus recently discovered can readily infect human cell lines. Given its similarity to a non-human primate oncogenic retrovirus, it would be wise to investigate the zoonotic potential of koala retrovirus. There is potential for this study to be performed at the Centers for Disease Control and Prevention in the US. A research grant will be sought to fund this work.

Theme 5. DROUGHT AND THE KOALA – A REGIONAL PERSPECTIVE

Changes in koala distribution and numbers in south west Queensland, 1995-2009

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Introduction

Climate change is affecting species distributions, leading to range shifts and changes in density and numbers within geographic ranges (Parmesan and Yohe, 2003, Thomas et al., 2006). Many populations at the contracting edge of a species range will be vulnerable to local declines arising from climate variability and weather extremes, which may affect a fauna species directly or by changing habitat quality and resource availability (Adams, 2010). Habitat loss and fragmentation are also important drivers of changes in species distribution and numbers (Fahrig 2003).

Koalas (*Phascolarctos cinereus*) are found across a broad geographic range in eastern and south east Australia, occurring in the states of Queensland, New South Wales, Victoria and South Australia. Their distribution is limited by climatic factors, the presence of suitable habitat and the ability to colonise new areas (Martin and Handasyde, 1999, Adams-Hosking et al., 2011). Since 2001, south west Queensland has experienced a severe and prolonged drought and anecdotal evidence suggested that regional koala numbers had declined.

This study aimed to update our understanding of the distribution and numbers of koalas in south west Queensland and to compare the results with those of a study in the late 1990s by Sullivan et al. (2004).

Methods

The study area was the South West Natural Resource Management (SWNRM) region, covering 187 000 km^2 of southern inland Queensland, Australia (Figure 1). In the 1990s Sullivan et al. (2004) estimated a mean number of 59 000 koalas in the region.

We conducted over 200 field surveys for faecal pellets in 2009, stratified by rainfall, latitude and habitat types (see Seabrook et al., 2011 for details). Surveys followed the spot assessment technique (Phillips and Callaghan 2000), searching a group of 30 *Eucalyptus*, *Corymbia* or *Angophora* trees for faecal pellets. We used fresh pellets to estimate koala density and numbers using a Faecal Standing Crop Method (FSCM) (Sullivan et al., 2002, Sullivan et al., 2004). The number of koalas was estimated using an area weighted average interpolated from the site densities, which was multiplied by the area of the habitat unit in which the site was found. We used bootstrap estimates to generate standard errors of population estimates.

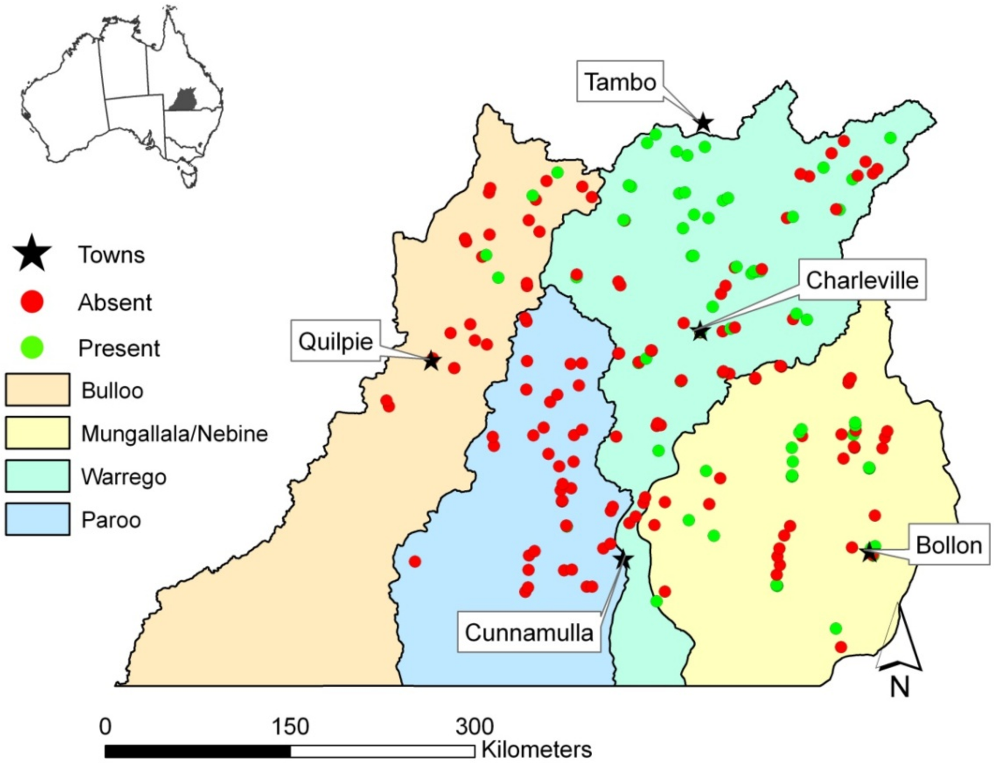

Figure 1 Koala distribution from faecal pellet surveys in the four major river catchments in south-west Queensland, 2009.

We examined historical climate data for the region (summer rainfall and number of days over 40°C) and estimated the area of land clearing (using data from The Statewide Landcover and Trees Study for the years from 1995-2008) to assess whether either or both of these factors might have contributed to a change in koala populations between 1995 and 2009.

Results

Koalas were found in the east and north east of the study areas, and were absent from the south and west (Figure 1). The most densely occupied area was between Charleville and Tambo, where all the sites had some signs of koala presence. Distribution had changed only slightly since 1995, although koalas seem to have disappeared from the upper Paroo River catchment.

The mean bootstrap estimates of total koala numbers were 11 634 (+/- 904 se). The overall decline, compared to the numbers estimated by Sullivan et al. (2004) in 1995, was 80% (Figure 2). The study areas did not overlap completely. However, only in the northwest region (pale green in Figure 2) were koalas present in 1995 in areas not sampled in 2009. Therefore, the variation in estimated numbers between the two years for this region is likely to reflect sampling differences.

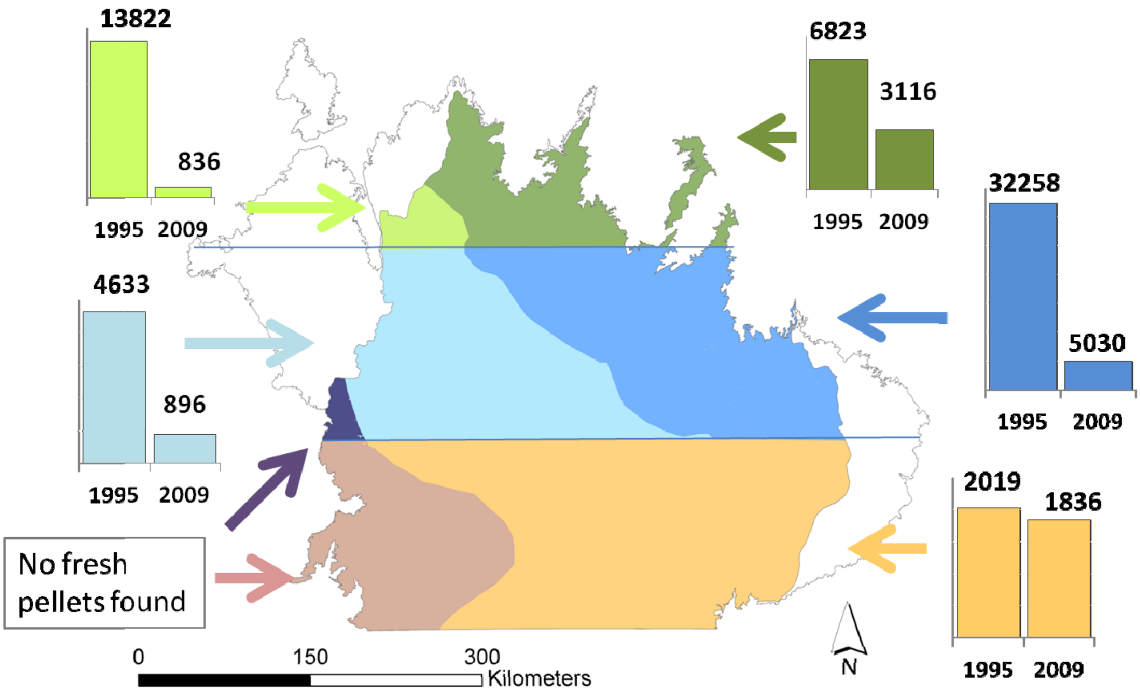

Figure 2 Changes in estimated koala numbers between 1995 and 2009 in the sample zones. The grey outline marks the Mulgalands Bioregion where the 1995 study was carried out.

Weather conditions and area of land cleared

Weather records show that between 2002 and 2007, Charleville, Bollon and Tambo had more than double the average number of hot days, with a peak across most of the region in 2006. There was also a much lower than average annual rainfall, particularly in 2002-03. The greatest amount of clearing (52%) had occurred in the eastern third of the region, with a trend of increasing clearing towards the south east. The habitat types with the greatest percentage of clearing were poplar box (*E. populnea*) and silver-leaved ironbark (*E. melanophloia*) (20.2%) and Thozet's box (*E. thozetiana*) and Dawson gum (*E. cambageana*) (16%).

Discussion

The results indicate that the drought from 2001 to 2007 has severely reduced the numbers of koalas in south west Queensland. They have contracted to the most optimal habitat along creeks and rivers, with little use of habitat away from water courses. The decline coincided with a period of 4-5 years where there was a combination of low summer rainfall and an above average number of very hot days, which mimic the predicted direction of climate change in the region, and which are known to affect koala survival (Gordon et al., 1988, Ellis et al., 2010, Seabrook et al., 2011). The most likely causes of the decline in numbers were climate extremes, particularly the combination of low summer rainfall and very hot days i.e. heatwaves. Koalas are affected by prolonged hot weather both physiologically (Degabriele and Dawson 1979, Adams-Hosking et al., 2011) and through a decline in the nutritional and water content of eucalypt leaves (Moore et al., 2004).

Land clearance and habitat fragmentation are likely to have affected koala distribution and numbers, particularly in the south east of the region. Between 1995 and 2008, 15-28% of high quality river red gum and coolabah habitats and 21-25% of poplar box habitat were cleared.

We conclude that drought significantly reduced koala numbers and they contracted to critical riparian habitat. This concurs with predicted range shift patterns for trailing edge populations. Management of koala populations in south west Queensland will depend on the identification and conservation of core habitats which act as refuges in times of drought, as well as secondary habitat which can be used for population expansion in good seasons. Monitoring changes in distribution and numbers at the limit of a species' range during conditions which mimic those predicted under climate change scenarios will help identify and manage the effects of climate change.

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Koala reproduction and the effect of drought in central Queensland; lessons from the Koala Venture project

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This paper examines how drought has affected breeding in koalas at two mines studied under the Koala Venture Research Partnership (See FitzGibbon et al. page 16 this volume). The Blair Athol Coal Mine is dominated by poplar box (*Eucalyptus populnea*) and ironbark forest (*E. crebra*) while the Clermont Coal Mine is dominated by coolabah (*E. coolabah*) woodland with black tea tree (*Melaleuca bracteata*). At each of these sites we catch koalas and examine them for body measures/morphometrics, take samples (tissue, blood and swabs), do a basic health assessment, examine females' pouches, and fit koalas with tags and collars before release at the point of capture. This process takes about 30 minutes.

Pouch and back young are also examined, and we try to measure young to estimate their age from growth curves. Large young are tagged and tissue samples taken.

Data from southeast Queensland, St Bees Island and Clermont show that approximately 60% of koala births occur in the wetter months of the year (Figure 1). During these warm and wet months there is new growth on trees so presumably this is a good time for females to put on body condition while their young are small and then carry them through late stage dependency during the cooler autumn and winter months.

Drought influences koala habitat in various ways, including a reduction in leaf moisture content and the amount of new growth on trees, as well as nutrient uptake and availability for trees, which presumably reduces browse quality for koalas. Drought also reduces the number of trees available because of tree die-back. This reduction in environmental health during drought flows back to koalas causing them to suffer physiological stress. Further, drought is often associated with an increase in the number of days of extreme heat which can pose enormous physiological challenges to koalas; during such periods koalas have been known to descend trees and sit on the ground in the shade or even in logs, as well as seek water to drink or rest in. As a result of these environmental conditions, drought can result in immunosuppression and reduced body condition, which increases susceptibility to disease and predators. However, drought is natural and is likely an important period of selective pressure upon populations but there are a lot of confounding influences that potentially compromise resilience to drought, such as habitat loss.

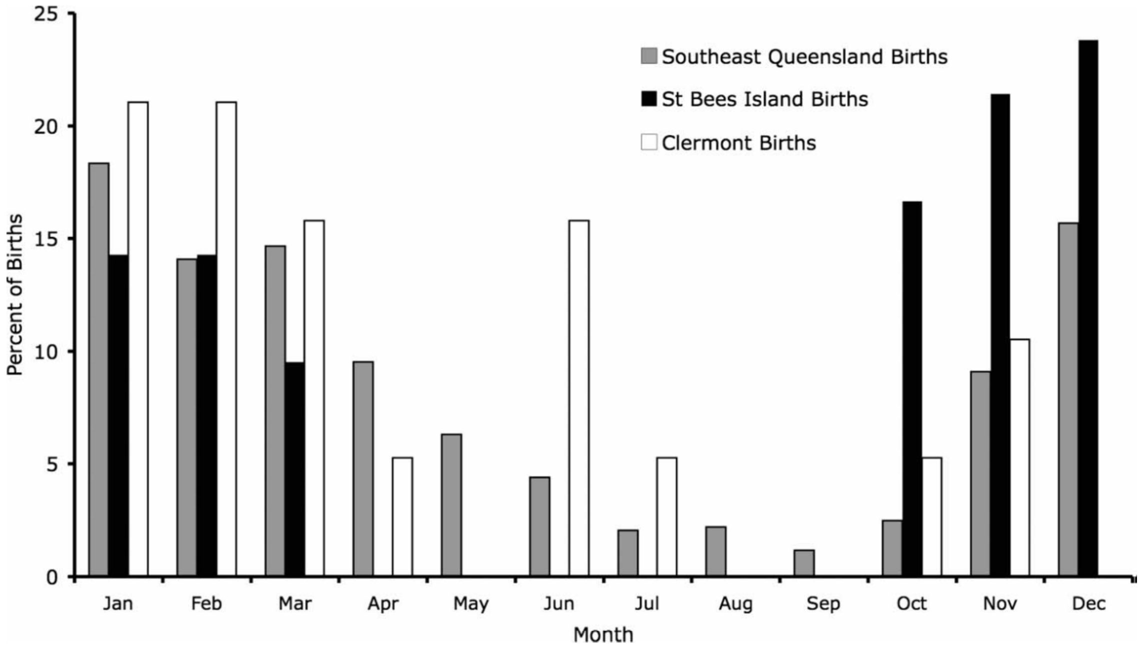

Figure 1 Koala births are generally concentrated in the wetter months of the year.

Drought at Blair Athol and Clermont Coal Mines

At Clermont there was an extended period of drought from 1990 until the late 2000's, with very few years of at least average rainfall (about 660 mm/year) during that period (Figure 2). In the early to mid-1990s there were several continuous years of very low rainfall, then a few years of average rainfall, followed by a further 6-7 years where rainfall dropped again to well below average (Figure 2). Somewhere around 2008-2010 the drought was considered to have broken in the district after several years of reasonable rainfall (although 2009 was another dry year).

During the period from 1994 to 2011 our monitoring program included 47 female koalas. The data on breeding in this sample show low proportions of females carrying young during the drought years (Figure 3). Some females still carried young in the early 1990s but in reduced numbers and by 1998 and 1999 there were no females found with young. It was not until two years after the drought was considered to have properly broken (around 2008) that a considerably greater proportion of female koalas were found carrying young (>50% compared to approximately 20-30%).

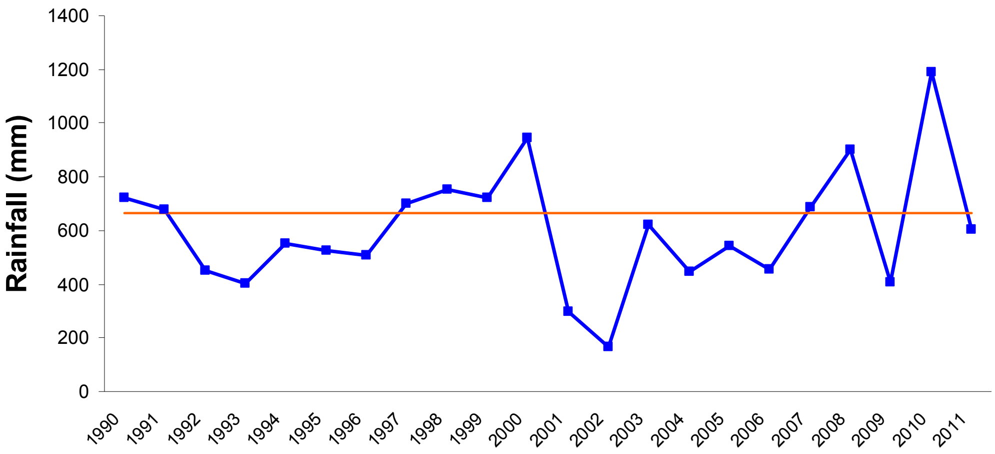

Figure 2 **Annual rainfall at Clermont (1990-2011); the orange line shows the average annual rainfall (660mm).**

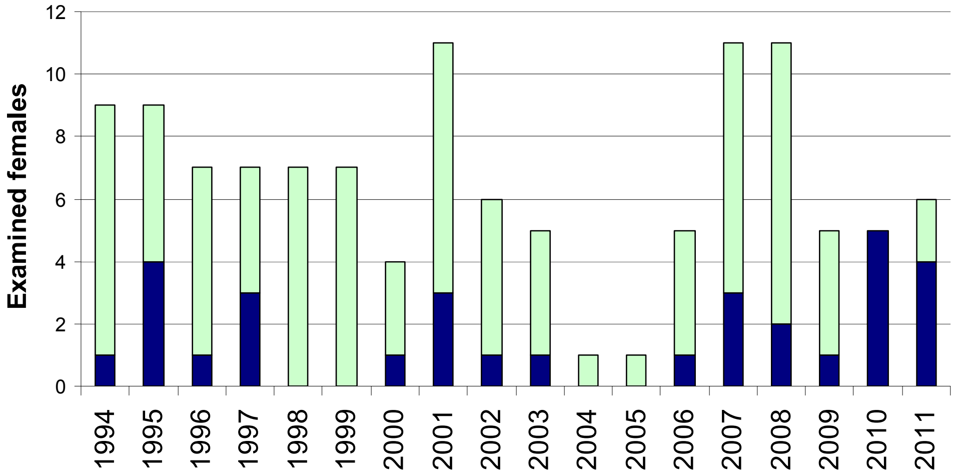

Figure 3 **Reproduction in examined female koalas at Blair Athol and Clermont Coal Mines. Blue bars show females with young, green bars show females without young.**

When the average annual rainfall is overlaid onto the figure showing percentage of breeding female koalas the two somewhat track each other (Figure 4). Last year (2011) all five adult female koalas that were tracked were carrying young. A lot of these females are the same females that were monitored during the drought. These data were collected during four 7-10 day field trips per year and where we attempted to catch each koala at least once a year, so we are confident that any young present would have been detected.

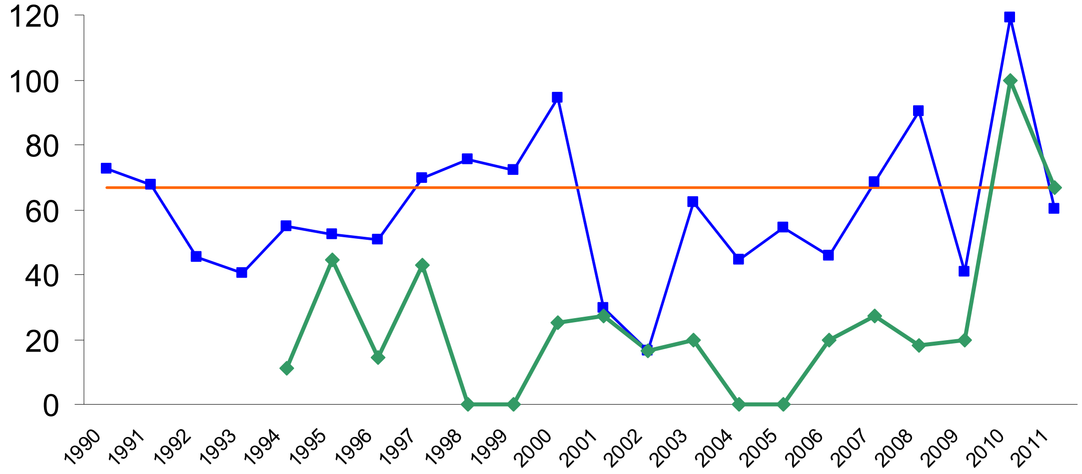

Figure 4 **Percentage of breeding females (green line; left y-axis) overlaid with annual rainfall (blue line) and average rainfall (red line) at Blair Athol and Clermont Coal Mines.**

When we examined how many young each female koala produced during their life we found that maximum fecundity was approximately one weaned young every two years (throughout the entire lifespan). However, some koalas produced as few as one young every five years. The number of young produced varies throughout the female koala's lifespan – for three to four years post-sexual maturation they seem to go into a productive period and then their reproductive output slows down again. We're not sure exactly how drought is reducing fecundity. We don't yet know if the koalas are still mating but not conceiving, or conceiving but not carrying their young successfully. We are also unsure how drought affects recruitment into the breeding population. Although it seems reasonable to assume that the survivorship of weaned young is depressed during drought periods, we don't yet know the magnitude of this effect.

Drought has a non-uniform influence across habitats even over a very small range. There is only a 6 km range between the two mines we examined, but the trees in these two locations deal with drought very differently. Riparian environments are generally more densely populated by koalas during favourable periods but they are also more susceptible to drought than the trees on the plains surrounding them. So the non-riparian zones are vital for koalas during dry spells, and it is possibly these areas that become important refugia during drought

Acknowledgements: UQ staff, RTCA staff, people of Clermont, koalas of the region, photographers.

Drought and the koala: two case studies from the central highlands

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Introduction

This paper is one of a set of three examining different aspects of drought in koala ecology. Seabrook et al. (see page 86 this volume) are presenting a landscape scale perspective and FitzGibbon et al. (see page 91 this volume) discuss the influence of relatively mild drought on a koala population. Here we present an account of the impact of more severe drought and then provide the outline of a conceptual model of koala dynamics under drought. We also raise questions that could be tested against such a model.

Context

There has been a general drying trend in eastern Australia's climate over last few decades as well as an increase in temperature. From the point of view of koala habitat (trees) there are other climatic measures that are relevant. For example the average number of consecutive dry days is important in understanding plant resilience in drought. These statistics (from the Australian Bureau of Meteorology) are known for Australia over the last century (Figure 1). They could be derived for any particular region or period although here we look at the national data set to illustrate the point. In the 1990s there were spikes in high numbers of consecutive days without rain. The year 1994 was among the top three years for that century, and 1991 and 1997 were also very high. These results are comparable to the big drought at the start of the 1900s.

During the recent drought (mid 1990s and again in early 2000s) there were widespread reports of tree and forest dieback from the coast to the ranges across central Queensland. The Koala Research Centre (KRC) received reports of distressed koalas wandering during the day, moribund and dead koalas curled at the base of trees in the downs country, many koalas with "dirty tail", and reports of local residents searching their region in vain for koalas at places formerly renowned for koala abundance.

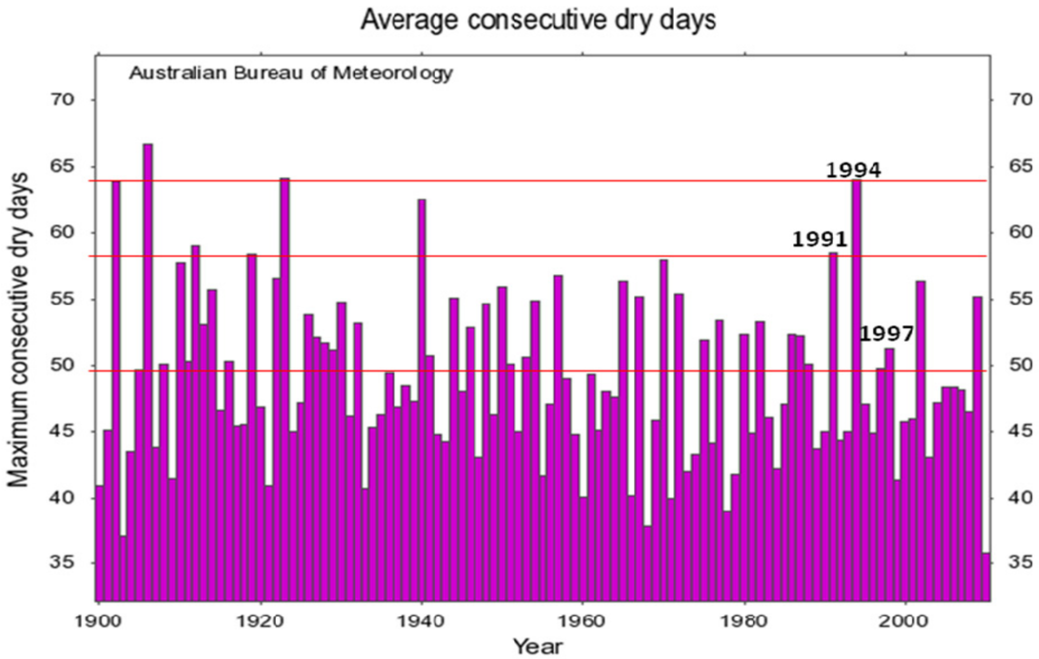

Figure 1 Average consecutive dry days since 1900, showing recent peaks in 1994, 1991 and 1997.

Case studies

Two cases from that period are discussed below. The first is from Springsure and the second, lesser known case is from Blackdown Tableland. However similar situations were reported from other locations including Hughenden and Tambo.

Case 1 – Springsure

In the Springsure region the drought caused extensive regional death of stream fringing vegetation – which consists almost universally of Queensland blue gum (*Eucalyptus tereticornis*), and also some river red gum (*E. camaldulensis*). Data on koala densities was gathered in the early 1990s at four connected sites around Springsure:

- Norwood Creek in the Minerva Hills west of Springsure, and
- Wallalee, Koala Creek and Pinnacle which are east of Springsure and downstream in the alluvial blacksoil plains.

When those properties were initially surveyed in 1992 koala densities ranged from up to 0.4 koalas per ha to 0.02 koalas per ha. In 2009 the sites were resurveyed and revealed a collapse in koala densities at Wallalee, Koala Creek and Pinnacle. However koala densities at Norwood Creek had stayed the same (Table 1). Why had koala densities at Norwood Creek not declined? There was tree death as this site as well, but the koala population didn't appear to have been affected in the medium term.

Table 1 Koala densities (koalas/ha) at four contrasting but connected koala habitats surveyed in 1992 and 2009.

Site	1992	2009
Wallalee	0.40	0.02
Koala Creek	0.15	0.00
Pinnacle	0.05	0.00
Norwood Creek	0.02	0.02

Another question that arose was why did the Queensland blue gums die when other tree species survived? The stream fringing forest at Wallalee and Koala Creek included coolabah (*E. coolabah*). This species didn't die during the drought.

The pattern of tree decline reflected our understanding of eucalypt species' capacity to manage water deficit. This is largely achieved through stomatal control. For example on Norwood Creek we looked at the capacity of various species to manage water deficit over a day (Melzer and Walsh unpublished data). Figure 2 illustrates the response of two species by way of example. The relative water content (%) of narrow leafed ironbark (*E. crebra*) recovers to 75% by middle of the day whereas the capacity for stomatal control of the Queensland blue gum (*E. tereticornis*) is much lower, and by the end of the day relative water content in foliage was at a minimum. It was found that the eucalypts growing on alluvium had a relatively low capacity to manage moisture stress and the species with the lowest capacity to manage water stress was Queensland blue gum. Other tree species suffered on the alluvium as well but they were more tolerant of moisture stress than Queensland blue gum.

So we propose that the koala population survived at Norwood Creek because the adjacent rocky ridges have stands of narrow leafed ironbark, which has a high capacity to deal with water stress and that the aquifer in the underlying rock was sufficient to maintain these drought tolerant trees. By way of contrast, on nearby self-mulching clay soil slopes, mountain coolabah (*E. orgadophylla*) had an intermediate tolerance to water stress. Further away from Norwood Creek there were reports of koalas dying in mountain coolabah woodlands on clay downs although the trees subsequently survived.

An analogous situation occurred at the Wallalee, with Queensland blue gum dying and coolabah surviving, but without the drought resistant species on adjacent ridges to provide water resources the koala population collapsed.

So, a cracked rock aquifer in the mountain and ranges had sustained the drought resistant tree species sufficiently to allow the associated koalas to survive the drought. On the alluvium the system dries to such an extent that the koalas couldn't persist and Queensland blue gum trees die and drought causes a permanent loss of critical features.

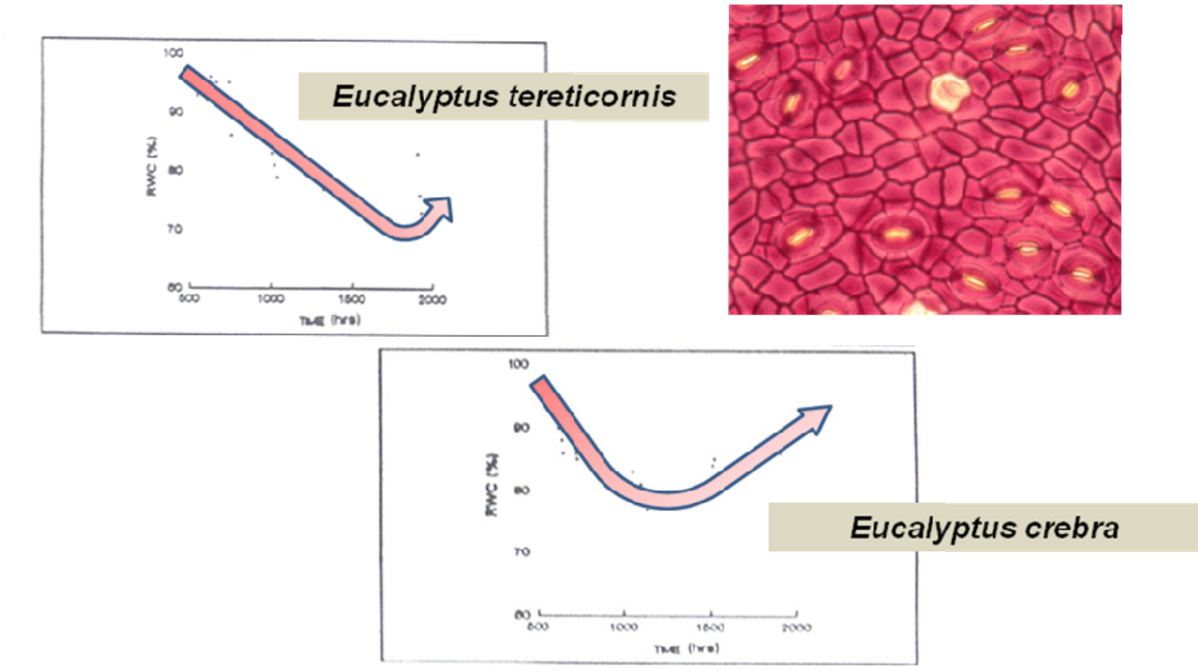

Figure 2 Stomatal control of narrow leafed ironbark (*Eucalyptus crebra*) and Queensland blue gum (*E. tereticornis*).

At Norwood Creek the location of the aquifers meant that the drought caused koala deaths in some spots and not in others. In locations further from aquifers even the tree species that were able to deal with the drought still had low leaf moisture and couldn't sustain koalas, whereas the rock aquifers maintained a leaf moisture content in narrow leafed ironbark foliage that were sufficient to sustain koalas.

In summary, there has been a general drying out across the Springsure region, with critically low leaf moisture and adverse weather conditions over at least the decade spanning 1990-1999. During this time koalas died and populations declined – some to local extinction. The tree species least capable of regulating their leaf moisture died, while more tolerant species persisted, recovering after significant rainfall. Where suitable conditions persisted, koala populations were maintained. Recovery of koala populations in this region will be slow, as there is no evidence of the reestablishment of Queensland blue gum. Based on anecdotal accounts koala populations are expected to take about 30 years to recover.

Case 2 – Namio Hills

In 1991 researchers caught koalas in various eucalypt species growing among budgeroo (*Lysicarpus angustifolius*) low forest on skeletal sandstone ridges. By the mid-1990s the koala populations had disappeared.

In 1994 they surveyed upper Charlevue Creek on "Namoi Hills" near the Blackdown Tableland. There were no koalas or signs of koalas in the stream fringing Queensland blue gum woodland on the alluvium. However koalas were found among the low hills and colluvial slopes of Blackdown Tableland, near the headwaters of the stream, and in the narrow leafed ironbark emergent from rosewood (*Acacia rhodoxylon*) on sandstone ridges.

On the undulating plateaus the koalas disappeared during the drought. Koalas were also absent from stream fringing woodlands. The only place koalas remained during the drought was in the foothills of the ranges.

Overview of case studies

Generally it is seasonally dry in central Queensland, and koalas are often found in xeric habitats among dry rangelands where they persist through drought. Common factors are persistent rock aquifers with suitable fodder species tolerant of environmental water deficits – commonly but not always narrow leafed ironbark. In seasonally dry environments stream fringing forests are not refuges in extreme events as alluvial aquifers are vulnerable to drying out, and Queensland blue gum has a very poor capacity to control water loss.

A general model of Regional Population Dynamics

A Source-sink model is proposed that includes:

- colonisation of lowlands from the refugia during relatively mesic periods;
- contraction in range during the xeric periods;
- expansion period – 30 years (from colloquial accounts);
- contraction period – gradual drying out of landscape then rapid, catastrophic (observation) decline in koala numbers;
- relatively high abundance koala populations on fertile/productive lowlands are less important for long term koala conservation than low density populations persisting in the rangelands; and
- refugia may be based around other persistent aquifers with suitable fodder species.

Based on this model likely local koala drought refugia are proposed in the Minerva Hills, Expedition Range and Blackdown Tableland, Kroombit Tops, Clarke and Connors Ranges, and Canarvon Ranges. More widely, the headwaters of major western catchments are likely refugia for koalas during drought.

WORKSHOP SESSION 5: Conceptualising drought responses at a local and landscape level

Koalas have lived with drought for millennia; however the mechanisms behind this persistence have not been considered in detail. Recent population collapses and accounts of populations persisting despite drought in central Queensland allow us to propose a population scale drought response operating at an annual and multi-decadal timeframe. We consider there are probably two dynamics operating. At the seasonal timeframe a persistent local population must have a local (home-range scale) dry-season refuge. At the multi-decadal timeframe a persistent population must have a regional (landscape scale) refuge. Here populations may persist while surrounding local populations die out. Two factors were considered essential in a drought refuge. These were a persistent aquifer such that the eucalypts forming the koala diet maintain foliar moisture sufficient to sustain koalas during drought, and a habitat structure that allows koalas to find sufficient shelter to maintain adequate thermoregulation. Fundamentally the effectiveness of any refuge is determined by the persistence of the aquifer. The nature of a refuge is defined by the hydrogeology of the landscape and the capacity of local eucalypts to manage water deficits. Empirically, koalas survive in riparian open forest/woodland in south west and north west Queensland while rocky hills and ranges provide refugia in Queensland's central highlands at least.

The dynamic of the drought response-response model is one of population decline and range contraction during drought followed by population increase and range expansion during wetter years and aquifer recharge. However, species with such a dynamic of range contraction and expansion are expected to be highly vulnerable to habitat fragmentation – especially if the rate/frequency of landscape disturbance is high relative to the rate of range contraction and expansion. Conversely, the more intact the landscape the more resistant the ecosystem would be to environmental challenges. The impact of drought varies spatially and with the duration and frequency of extreme weather events occurring during the drought. While we currently believe that extreme heat waves and extended periods of consecutive rain free days are significant factors in respectively determining koala survivorship and habitat persistence, there is a need to more clearly define the environmental parameters that work in concert to limit the survival of a local population or its habitat. Given that there is an expected 50% decline in Australian rainfall and an increase in the frequency and extremity of severe weather events by the end of the 21st C, understanding these limiting parameters becomes critical for future conservation management. Similarly it is important to be able to recognize the characteristics of potential drought refugia and to work towards their conservation. The uncertainty around the medium to long term Australian climate has implications for the design of post-mine revegetation and habitat restoration works. Location of these works needs to take account of the security of aquifers and the persistence of soil moisture. This may lead to some counter-intuitive choices of landscape for restoration (e.g. rocky ridges). Further the choice of tree species should involve some consideration of the inherent capacity of that species capacity to regulate moisture loss (drought resilience).

Our hypothesis suggests that (1) Queensland's koala populations will be derived from foundation populations centred on long-lasting refugia, (2) these populations will have a long history of contraction and expansion from refugia, and (3) each population is likely to have a distinct genotype reflecting the size of the founder population during periods of contraction and the degree of gene exchange between populations during periods of expansion. If it exists such a genetic signature could be used to identify the location of likely refugia. However, the absence of the genetic signature would not necessarily negate the refugia hypothesis.

The consensus of survey data, natural history observations and modelling is of a broad decline in population density across the state and a contraction in range from the west to east. In regional areas this decline has been associated with the drought of the 1990s/early 2000s. Subsequent *La nina* conditions have seen a state-wide recharge of aquifers and a return to optimal growing conditions for eucalypts. A response in local koala populations is expected and monitoring needs to commence to follow any local population increases and any expansion in the contracted range of the koala. Anecdotal accounts after drought early in the 20th C suggested a 20 year recovery interval for western koala populations. More recent accounts (1980s) suggest a 30 to 40 year recovery. If these two different estimates reflect a real change in the recovery period, there is clearly a complex long term dynamic at work. We speculate the dynamic could be influenced by landscape changes such as broad acre clearing, changes in plant community structure and composition, variables such as a change in the frequency and severity of extreme weather events, or a lower founder population than in the Federation Drought. It is clear that the conservation of the koala requires observational data from widespread monitoring over decadal timeframes.

Theme 6. KOALAS, HIGHWAYS AND ROLLING INFRASTRUCTURE

Koalas and roads: a case study in Ballarat, Victoria

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The case study on koalas presented here is based on data gathered during my work as a researcher in Ballarat, Victoria. These data are complemented by habitat mapping from the Koala Plan of Management for Ballarat (City of Ballarat and Australian Koala Foundation (AKF)), and wildlife carer data. These data form part of an ongoing doctoral research program.

Historical background

The koala was hunted to extinction in most parts of mainland Victoria except for remote areas of Gippsland. A huge amount of land clearing has occurred since European settlement; Victoria is one of the most cleared Australian states, and the impact is quite significant.

About 70% of koala habitat was removed throughout the state resulting in significant koala population fragmentation; on private land up to 90% has been removed.

In Victoria, there is also a long history of translocation of koalas; a very controversial topic. Some animals were taken to French Island in the early 1900s and later to other islands as well. Koalas in Victoria overpopulate on islands, they breed up, inbreed, and can't disperse, so for the last 80 years, the government has taken koalas back from these areas and recolonised the mainland. Unfortunately, koalas were also placed into isolated bushland on the mainland which has caused further overpopulation in these fragmented areas. As a result the koala gene pool in Victoria is very small. An example of the significant effect of inbreeding on koalas can be seen in the koalas taken from French Island to Kangaroo Island (probably for tourism) – a significant proportion of these koalas have, for example, only one testicle.

Nowadays translocation no longer occurs on such a large scale. There are now efforts to sterilise, or introduce fertility control to inbreeding koala populations, and there is a focus on keeping koala numbers low. It's important to remember the reality of the situation is not an overpopulation of koalas but an under-population of trees.

The current koala problems in Victoria are similar to the rest of Australia – loss and fragmentation of habitat, diseases as well as dogs and roads. A large proportion of suitable habitat is on private property and roadsides, both of which are under the management of councils. Anecdotal evidence and community surveys indicate a declining koala population. Official documentation says there is an overpopulation problem but there are no effective surveys of koala population status to confirm that view.

Ballarat case study

Ballarat is a prime example of the situation in Victoria more broadly. The historic developments of gold mining, farming, and population growth are combined with current residential developments and population projections of 70 000 more people by 2050.

Triggered by witnessing a large number of koala road kills over many years, I began a study that aimed to identify koalas' use of roadside habitat and their chances of survival. The first step to minimising road deaths of koalas around Ballarat was to collect the data.

Wildlife carers in Victoria are not as organised as in Queensland – there is little formal structure or proper data collection. I collated 15 years' worth of data obtained from wildlife carers in Ballarat and the Mornington Peninsula in paper form. I analysed the data, and the preliminary results showed that about 40-50% of koalas in shelters were admitted because of collisions with vehicles, another 40% had been attacked by dogs. Eighty percent of koalas in shelters died. That was 15 years ago but still the majority of koalas in wildlife shelters die, as well as the ones that die at the side of the road and never make it in to a shelter. It is a very unsustainable situation. How many dead koalas are never found? How many of the 20% that are returned to the wild actually survive?

One wildlife carer I spoke to, only recently began to ear-tag all released koalas to see if they survive – but it's not radio tracking, and good data is very limited. My concern is that a large proportion of koalas released from care might not survive.

The second step of the study was to plot the carers' data on a map to identify koala roadkill blackspots. I also added additional sightings of roadkill from other sources.

I wanted to capture some koalas from the blackspot areas to see if they were living there or just moving through, and if they were zigzagging across the roads. We captured two koalas from the roadside vegetation on the highway and one from the roadside vegetation along a minor tributary road to the highway. The three koalas were followed for a while – both of the highway koalas died within 3 months, one koala living on a side road survived the duration of the study. It was found that koalas were using traditional food trees but also using non-traditional trees like pines, wattles and non-indigenous eucalypts, probably for shelter.

Questions: How many koalas are occupying the roadside vegetation? Are these transient koalas or do they establish permanent home ranges? How large are home ranges compared to a healthy forest? What are the species of trees they eat?

A more detailed study followed. I selected a black spot and in one day captured every koala that we could see and followed them for six months. I identified and measured every tree in the blackspot and also looked for evidence of koalas in the area, such as scratch marks, scats, presence of koalas, and recorded 10 000 trees in a database. The area around Ballarat has been classified into its *Eucalyptus* communities and then mapped to AKF's koala habitat atlas, so that was available for use and we extended this with our own mapping using the same methodology. The koalas were radio tracked, sometimes three times a day, to see what times of day they move, what trees they use for shelter, and their diet. A researcher from the University of Sydney was commissioned to look at koala scats using electron microscopy to confirm diet.

The results of the study showed that of nine koalas, one died of collision with car. The koalas ate traditional foods, but there was also evidence of non-traditional food sources including wattles, pines and non-indigenous eucalypts. One koala regularly ate pines; this individual was sitting for six months in two trees, one Manna Gum and one pine. This was the exception, but that koala must not have been able to get enough nutrition from the Manna Gum, so it probably supplemented its diet with pine. We also found a lot of koalas eating wattles (up to 10% in some cases), and non-indigenous eucalypts were also eaten. The most dominant koalas had the smallest home ranges in the best quality habitat. They also had the fewest highway crossings. A dominant male had two to three trees; a female that stayed with him had five trees including his trees, and didn't move across the road.

The final aspect of the project will be a statistical analysis of koala roadkill blackspots; including assessments of sections of the highway for traffic speed as well as distance to koala habitat, amount of koala habitat available, quality of habitat, and driver visibility. The data will be worked into a model to predict koala roadkill blackspots in other areas.

The city of Ballarat is now the first city to have a koala management plan. Koala habitat is protected under the plan, and permits are needed to cut down trees for houses, roads, etc. Habitat has been mapped into types of *Eucalyptus* communities (Figure 1), and this has been extrapolated to create a koala habitat map (Figure 2) and a koala planning map (Figure 3). The best koala habitat is at Mount Buninyong and surrounding areas. Primary (P) and 2A habitat is marked and buffers are placed around it and overlaid with linking areas to ensure protection, proper planning and hopefully rehabilitation.

Further work I want to carry out for this project includes comparing tree preference of koalas (determined by scats and scratch surveys) to the diet study and the radio-tracking results, as well as analysing the impact of weather on tree selection and koala movement.

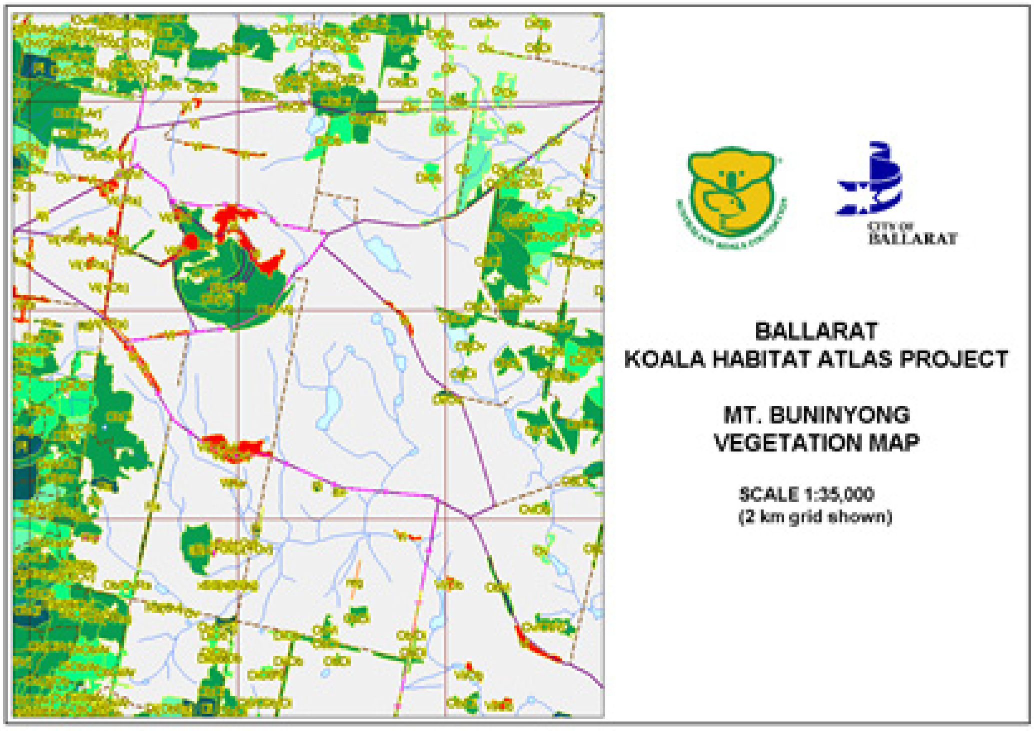

Figure 1 Vegetation map of Mt Buninyong.

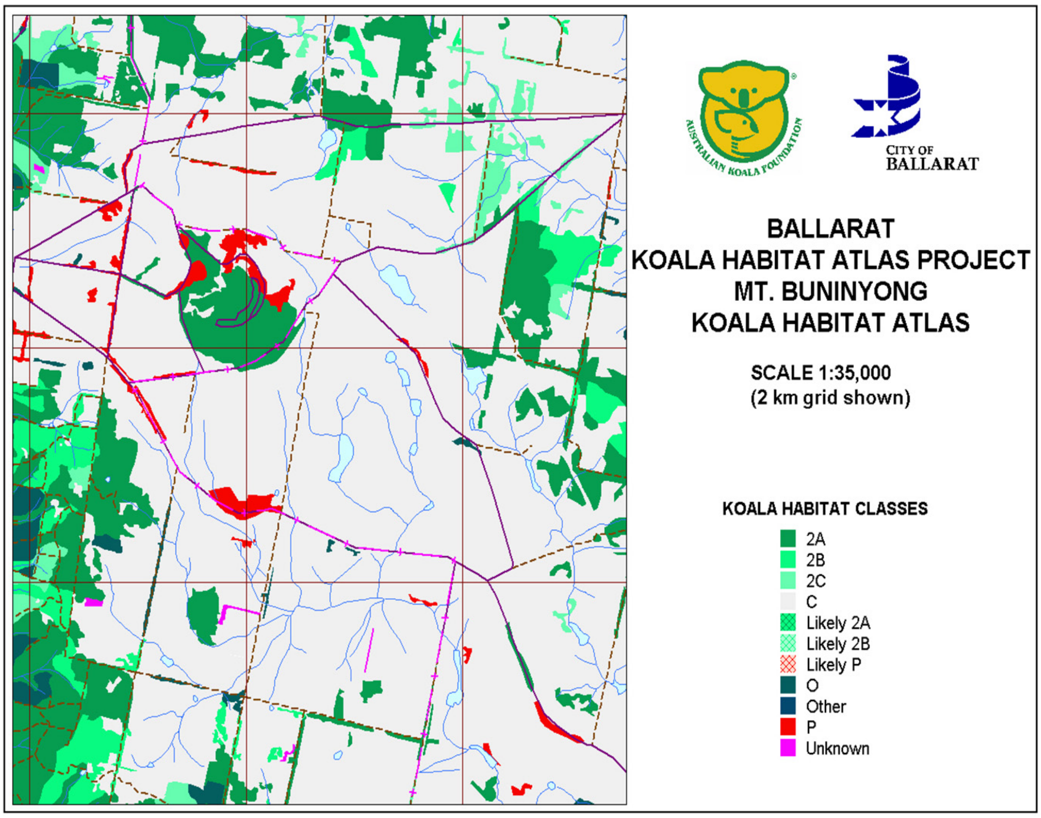

Figure 2 Koala habitat map.

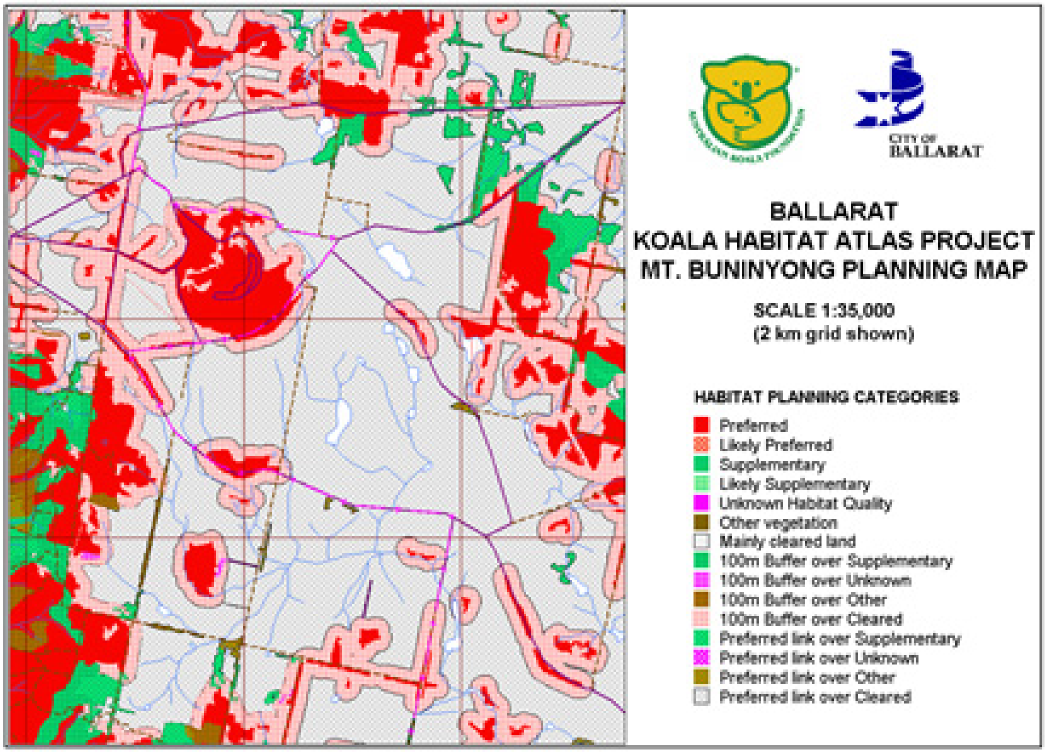

Figure 3 Koala planning map (Mt Buninyong).

Understanding the movements of koalas in a road-dominated landscape

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The "Koala Coast" zone is an extremely fragmented, human and road dominated landscape. People are arriving to live there at a rate of 500 people a week. However some sections of habitat still support wildlife. In the midst of thousands of people and continuous development, koalas are trying to live. South East Queensland's koalas are in catastrophic decline. There are three main causes of koala deaths: cars, dogs, and diseases (Figure 1).

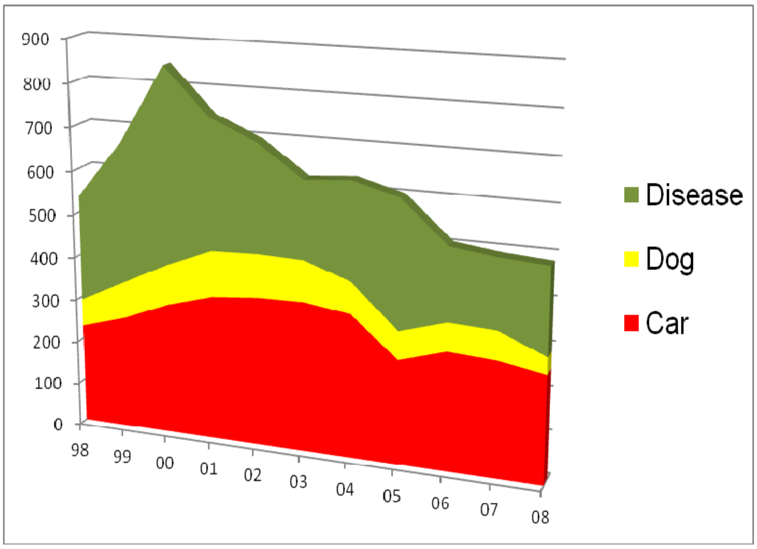

Figure 1 Causes of koala deaths in South East Queensland (as recorded by admissions of Koala Hospitals, DERM 2009).

Cars are the primary cause of death in South East Queensland. Animals also need to forage, to find mates, to obtain shelter and breeding sites and to participate in social interactions, and road systems impact on all of these functions by reducing the habitat connectivity. The Queensland Government has decided to do something about this, with the Queensland Department of Transport and Main Roads initiating the South East Queensland Koala Retrofit and Monitoring Project. The project aims to: reduce koala road mortality using mitigation methods; monitor koala movements, behaviour and habitat usage; and assess the use and effectiveness of retrofitted structures

We were invited to address these aims, adding the additional project aim of monitoring koala health and undertaking treatment as required. As well as ecological and behavioural work on the koalas, we perform a full health check, and if treatment is required, the koala is transferred to veterinary care.

The study sites discussed here are Petrie, Mango Hill (north of Brisbane), and Eprapah, Tingalpa and Alexandra Hills (in the Redlands area) (Figure 2).

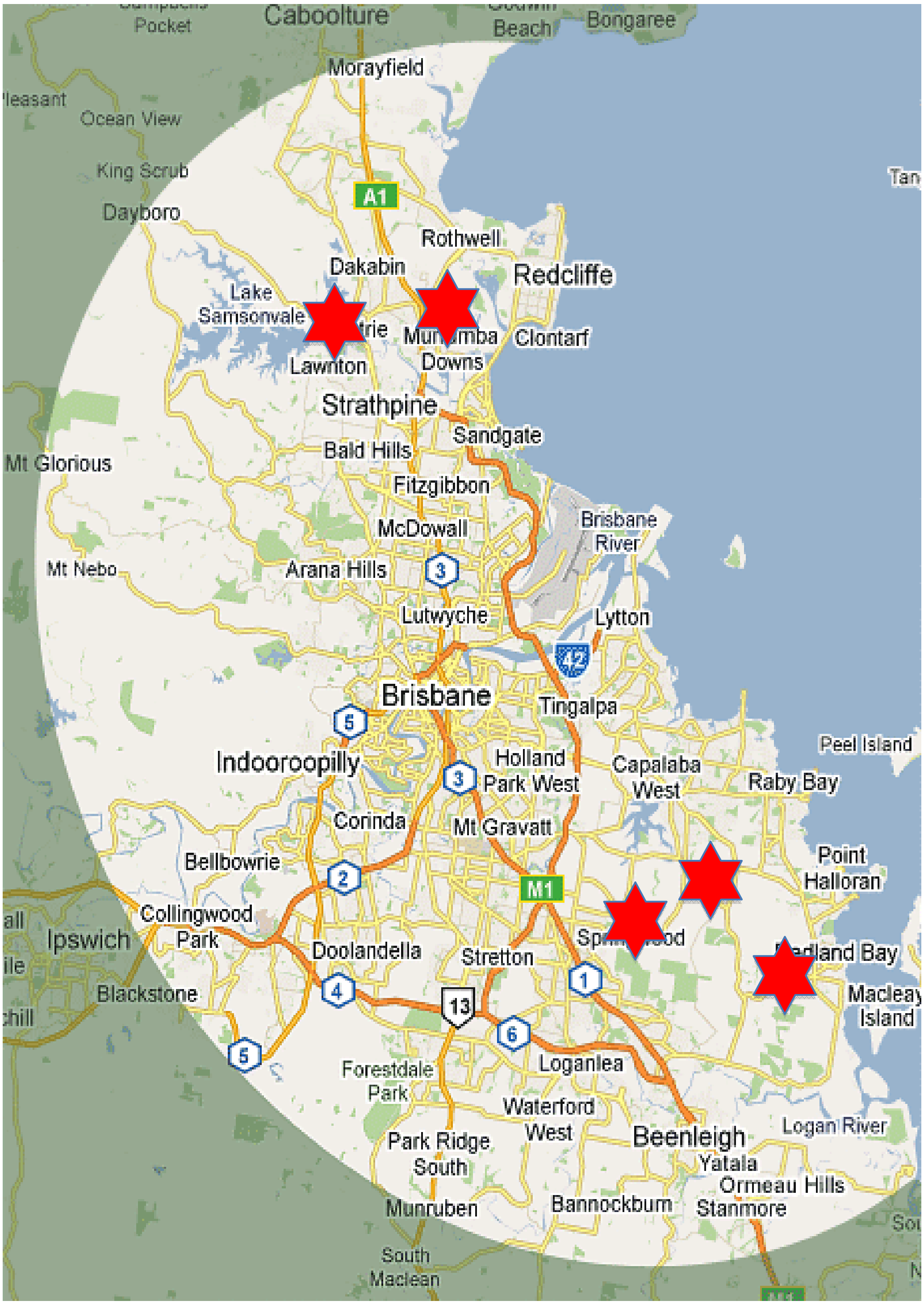

Figure 2 Study sites (Petrie, Mango Hill, Eprapah, Tingalpa, Alexandra Hills).

Under every road are a variety of bridges, tunnels, and culverts for the passage of water, which may or may not be used by koalas. We need to know which types of bridges koalas will use. For example, the addition of ledges to the inside walls of culverts that normally contain water allow koalas to cross without using the road. Fencing can be used to funnel animals towards structures or to prevent koalas going onto the roads. Fencing is normally not continuous as it is too extensive but might be possible along some stretches.

To understand koala movements in these highly fragmented sites we have caught 75 koalas at the five study sites since September 2011, and collared and released 62. The project is providing invaluable data on koala movement. Since they were released, four of the koalas have been killed by dogs. None of the collared koalas have been hit on the road so far.

Most koalas have ranges that include roads. A typical koala range is shown in Figure 3. Some koalas we are tracking spend most of their time literally in people's backyards where there are good food trees, traversing roads and dogs.

Figure 3 GPS movement records of a typical koala (note the lines are not indicative of movements, the dots are the measurements).

In Mango Hill there is a tiny sliver of bush that is being used by koalas. One koala tracked in this site walks a thin line around useful bush and goes into backyards (Figure 4). There are 11 koalas in that small zone of habitat. These koalas have a really different life to bush koalas.

Across the Bruce Highway there is another koala we are tracking that is spending its time in a swampy environment. Underneath Anzac Avenue there is a broad bridge that was rehabilitated so that koalas could move through it to get to the suitable forest habitat, but this tracked koala crossed the road during the night instead to get into the forest, returning again over the road in the morning.

Figure 4 GPS records from a koala at Mango Hill.

There are limitations to traditional telemetry methods. VHF technology revolutionised wildlife management when it was introduced, but it is hard work, and the results are limited by the time you spend looking for koalas. VHF also has difficulties with signal reception and loss. GPS collars are much easier to use. However, you still have to catch animals, the GPS collars are expensive, have limited deployment times, and there may be positional inaccuracies. Using GPS collars you frequently get false positive results that need to be constrained to believable data. But sometimes you really need to know if a koala you are tracking did or didn't cross a road.

WildSpy Pty Ltd, Brisbane, has come up with another technique, an ear-mounted apparatus for wireless identification (Figure 5). It is a form of active radio frequency identification, like the PIT microchip in pets, but it can be detected from a distance. The Wireless Identification (WID) apparatus is tiny enough for ear tags for small koalas or can be put on collars on larger koalas. Movements are detected by fixed dataloggers. WID tags "chirp" every 10 seconds and if the koala carrying the WID comes in range of a datalogger, the koala is detected, and the event is recorded with a time and date stamp.

We used this technology in the Petrie area, putting data loggers near a bridge to see if koalas were moving under the bridge. It was a broad bridge with koala forest on one side. Data loggers were mounted in place underneath the bridge at two locations. In conjunction with GPS data we can find precisely when the koala passed the data loggers – this confirms the koala really did move under the bridge. We now have photographic evidence of koalas using ledges installed underneath bridges. They are using completely new structures including concrete structures that we thought they'd never use.

The next phase in the project is the Redland Koala Overpass which will be constructed within a few months, and will be the world's first koala bridge.

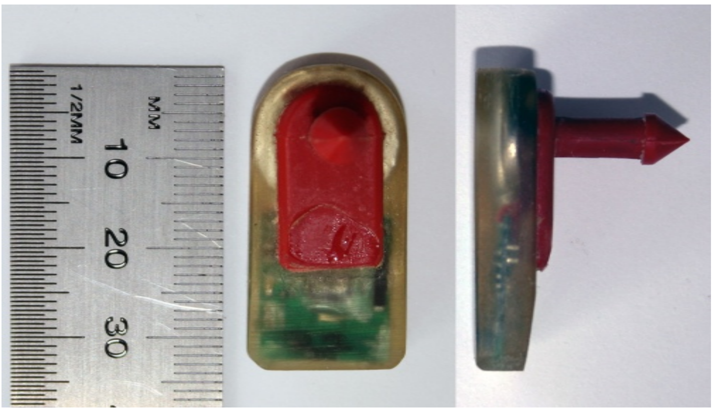

Figure 5 WID (Wireless Identification) apparatus (WildSpy Pty Ltd, Brisbane).

Reference

DERM. 2009. *Decline of the Koala Coast Population: Populations Status in 2008*. Department of Environment and Resources Management, Brisbane.

What do we know about CQ koalas near rolling infrastructure?

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When we talk about rolling infrastructure for koalas in central Queensland we are not just talking about bitumen and dirt roads, but also two major rail networks and haul roads and conveyer systems on mine sites.

Koala populations appear to occur in quite low densities but are widespread throughout central Queensland. After observing a lot of koalas killed on roads between Rockhampton and Mackay, and receiving an increasing number of calls and emails about deaths on the Peak Downs Highway, we started to look more closely into the issue to see what was happening and how it might affect koala populations in the region.

Initially, we collated all the calls and anecdotal records received during 2009 and 2010. Then in 2011 we enlisted public assistance asking for reports of koala sightings via SMS. We created a Wanted Poster and sent it to service stations along the Bruce and Peak Downs Highway. It was also distributed to all 228 primary and high schools from Proserpine to Gladstone and west to Longreach for their newsletters and noticeboards and to community groups and Landcare organisations in the region. ABC Radio and Channel 7 News supported us with interviews to help get the message across to the public. Members of the Koala Research Centre also keep an eye out during their travels and any carcasses in a fit state were collected to sample and measure where possible. Isaac Regional Council's road maintenance crew also collected and stored koala road fatalities for us.

The community was quite helpful and generally happy to contact us with koala sightings. When we were collating the data we found that some of the SMS messages were too vague to use with limited location details, and we were careful not to count any animals twice – we often assumed two reports were one animal if the reports were similar so the final counts are conservative (Table 1). We also personally checked some of the reports and locations.

Because people were not encouraged to stop and look at the bodies, we have limited data on the gender, age class or size of the animals killed. The animals that we were able to collect personally are the only ones we have any further details for (Table 2). During the last three years, the majority of the road deaths have been male, with a few records of females, including mothers with back young.

When the 2009 and 2010 data, and the 2011 SMS records were mapped, three road fatality 'hot spots' were identified (Figure 1). The first is a 42 km stretch of the Bruce Highway centred on St Lawrence. This region has numerous creeks and some continuous vegetation corridors. The second 'hot spot' is on the Peak Downs Highway along an 18 km stretch from the Eton Range to Denison Creek with evenly spaced fatalities for the entire stretch. The third 'hot spot' area was a short stretch to the north of Dysart where the highway crosses Downs Creek.

Information on the time of year shows most deaths occur towards the end of year, between October and December, but, as yet, this has not been fully analysed.

The Bruce Highway, which is the major thoroughfare from Rockhampton to the north, has a high traffic volume of approximately 2000 per day and this has been consistent for the past five years (Figure 2). In addition about 30% of the traffic is heavy vehicles. Along this stretch of highway, vehicles are permitted to travel at 110 km/hr, averaging one vehicle every 40 seconds. This gives the koala less than 40 seconds to cross the road.

The Peak Downs Highway only services mining and rural communities but traffic is steadily increasing as the mining industry expands (Figure 2). Despite heavy vehicle usage being roughly the same proportions as on the Bruce Highway, the faster moving light vehicle traffic is increasing and there is an average of one vehicle every 24 seconds.

Table 1 Koala sightings in central Queensland 2009, 2010 and 2011.

	Reports	Dead	Alive
2009	26	17	9
2010	20	13	7
2011	58	32	26
3 year total	104	62	42

Table 2 Koala deaths on transport corridors in central Queensland, with gender identified where known.

	Dead	Male	Female
2009	17	5	
2010	13	2	
2011	32	10	4
3 year total	62	17	4

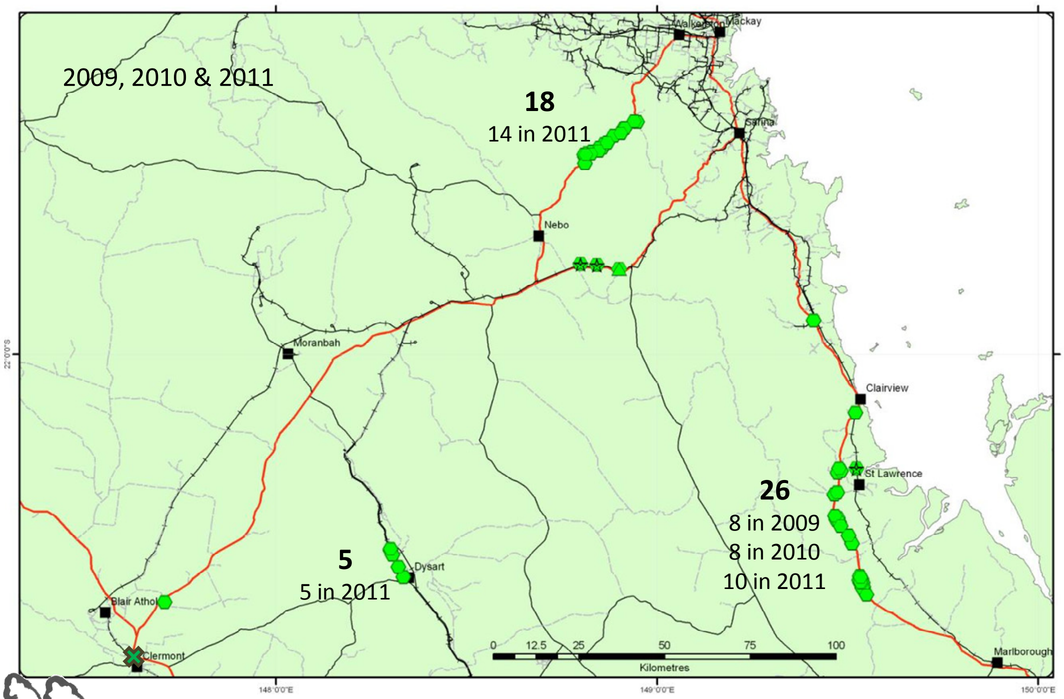

Figure 1 **Recorded koala road deaths in 2009, 2010 and 2011. Stars close to Nebo are train strikes.**

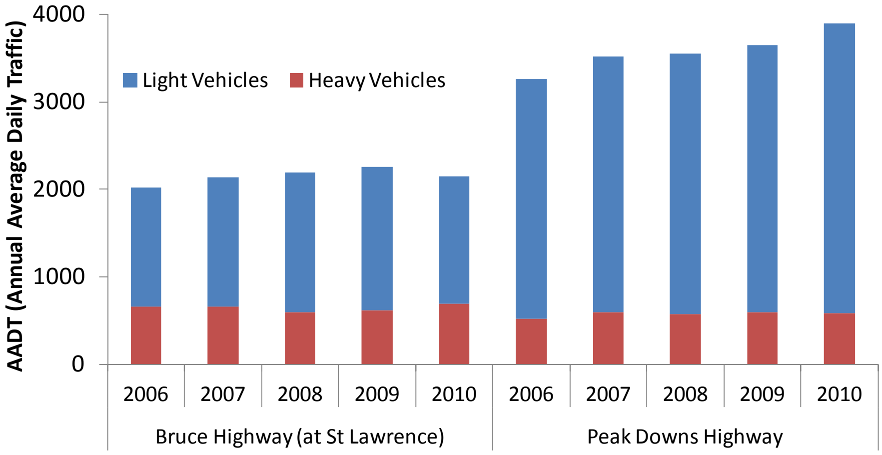

Figure 2 **Traffic volume on road segments with high numbers of koala deaths (vehicle data was supplied by request through the Principal Designer (Civil), Mackay/Whitsunday Region, Program Delivery & Operations Division, Department of Transport and Main Roads).**

There is some good news to come from the data – there are still live koalas in the area. Our SMS campaign was also asking for sightings of live koalas. We received many messages and reports from the public as well as workers in the area. For example, Ergon Energy workers who were upgrading powerlines sent photographs of koalas found during clearing under the lines.

A plot of both live koala sightings and koala deaths shows a continuous, but most likely low density, population throughout the northern areas of central Queensland (Figure 3). Koalas are fairly widespread along the Eton and Sarina Ranges with a gap (over mostly cleared land) to the west, before becoming more common towards Dysart and Clermont. There is a high concentration of koalas around the Sarina region, and there have been many recent sightings of koalas in this area where koalas previously weren't found, particularly close to and on the coastal strip.

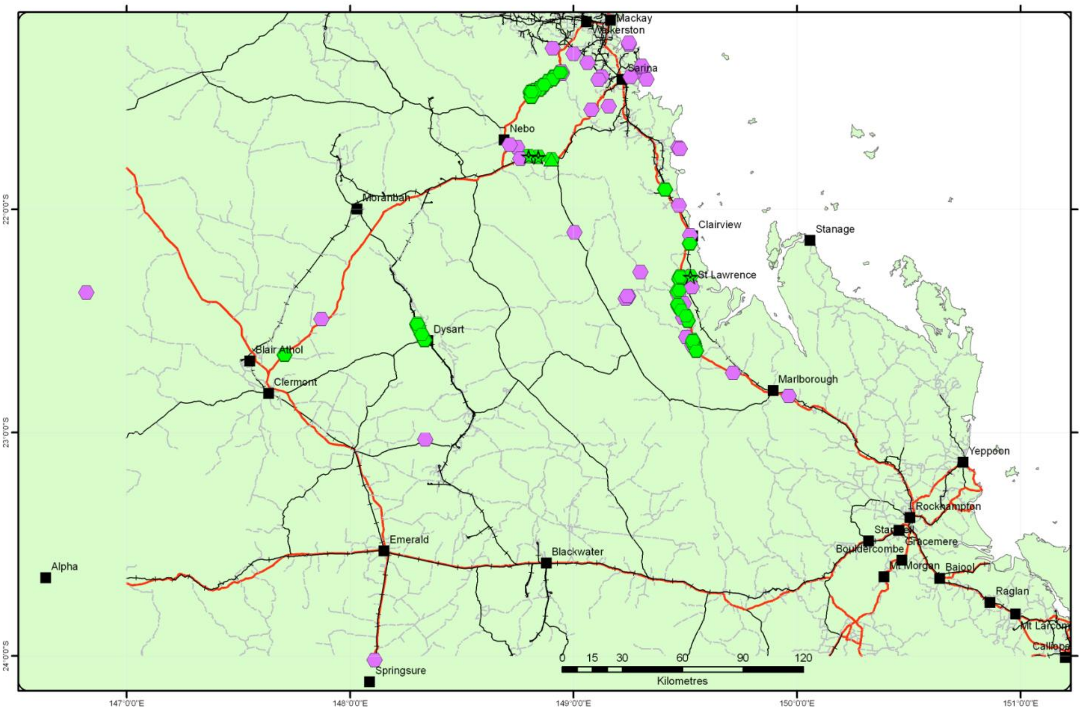

Figure 3 All koala sightings from 2009 to 2011, including dead (green) and live (pink) sightings. Green stars close to Nebo are rail fatalities.

The map also highlights a void in koala sightings in the southern areas of the central Queensland region, from Rockhampton/Gladstone and out to Blackwater/Emerald. This could be an artefact of the sampling as I suspect that there are koalas in this area, but they are definitely much scarcer than they were previously. We know in the 1990s there were frequent koala road fatalities around Gogango and Duaringa (at least) and, overtime, this mortality may have exhausted these populations as the road traffic in this region has also increased significantly.

To date, we have surveyed the St Lawrence region for a 40km stretch along the highway (5km on either side of the road), as well as some trips to other areas around Sarina, Flaggy Rock and Clareview. This hotspot area on the Bruce Highway has many records of live koala sightings in areas away from the highway. In contrast, the Peak Downs Highway hotspot has no "off road" sightings reported. The only live animals spotted on this stretch were seen on the road verge. This is likely to be an artefact of the low density human occupation of this region so surveying this area is a priority.

Acknowledgements: John Rolfe and Alistair Melzer.

WORKSHOP SESSION 6: Central Queensland highway and infrastructure corridors

For any rare, threatened or vulnerable animal avoidable causes of pre-mature death should be addressed as a matter of priority. This includes any impacts on koalas that are the direct result of human activities. For koalas co-existing with road and rail networks, urban development and rural activities strategies must implemented to limit human impact on both the koala and its remaining habitat.

Western central Queensland is experiencing a mining boom and the coastal regions are undergoing increased residential and commercial development. Consequently the native fauna are also under pressure.

Many factors affect the number of koala deaths that are occurring on the roads. Koalas are most active at night and are likely to be moving on the ground at dawn and dusk when visibility is lowest. These periods may coincide with driver fatigue and shift change times. Peaks in industrial and mine traffic volumes should also be investigated. In addition, the nature of the road stretches (straight or with bends) and the densities of koalas in the surrounding habitat are all important factors.

It is critically important to identify high impact areas and then examine adjoining habitat and local and regional koala populations in these areas to determine the impact road and rail fatalities are having on the long term security of central Queensland koalas.

There are many projects, both overseas and in south east Queensland, which are looking at the best practices for mitigating fauna road fatalities. This research needs to continue in order to find solutions to implement in existing and future road and rail corridors. Mitigation strategies that have already had some success in other regions include:

- underpasses with road side fencing
- increased lighting in high impact areas (however this is difficult on long stretches of highway which we find in central Queensland)
- reduced vehicle speed limits in high impact areas, particularly on secondary roads (although on central Queensland highways and railways at any speed a koala strike will almost always result in the death of the koala (no need to operate koala husbandry ventures)
- education and awareness programmes, and appropriate stagnant and active signage and
- reduced vegetation in road verges and median strip.

However, it is acknowledged that these strategies may be more difficult to implement in central Queensland due to the length of roads and rail involved.

As koalas are being killed on the roads, the underpinning concern is that koala populations in this region are not well understood so any impact will be unpredictable. The extent, density and basic ecology (recruitment, fecundity and health) of these populations are not known, so the effect of these increasing road deaths will have on the population is unclear. Continued fatalities of koalas in central Queensland, could potentially be detrimental to the entire population, as gene flow is interrupted and potential dispersal and migration options are diminished with the creation of ‘island’ communities barricaded by transport networks.

Theme 7. REGIONAL PLANNING FOR THE CENTRAL QUEENSLAND KOALA

South East Queensland Koala State Planning Instruments

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From 2008 to 2010 there have been progressive announcements from the Queensland Government on the South East Queensland Koala Response Strategy. Queensland Governments have focused on koala conservation planning since the 1990s.

In December 2008 the Koala Response Strategy was announced, following significant population declines since 2005 (around 50% in two years). A key component of the strategy is to develop stronger planning instruments than past and present policies (e.g. SPP 1997 and 2005, Koala Plan 2006). The strategy led to the creation of a new set of policies, government commitments and legislation aimed at preserving habitat qualities across South East Queensland (Koala Coast and Pine Rivers). There was an aim to build on what had been done in the past, and strict interim State Regulatory Planning Provisions were immediately put in place to stop pre-emptive clearing permits getting approved before the legislation changed, particularly in key habitat areas such as Pine Rivers and Koala Coast, and to regulate development until the final policies were released.

There were three fundamental decisions in developing the new planning framework for koala conservation:

1) Determine habitat value matrix – South East Queensland Koala Habitat Values Map (data on which to base this map are critical and one of the most important things you can do on your journey to consider planning is to make sure you can point to koala habitats spatially).
2) Identify best strategy to deal with existing developed areas and future land use planning.
3) Identify applicable area – where koala populations are at most risk from habitat loss and unsustainable mortality: vehicle strikes, dog attacks, stress-related diseases.

The long data sets for the Koala Coast and Pine Rivers areas were instrumental in these decisions. The statistics were undeniable and carried the day. Populations at risk of vehicle strike, dog attack, etc, were identified and we set about dealing with them. Habitat protection was the overriding goal, and other programs were built around that core objective.

The resulting statutory instruments, released on 31 May 2010, are the South East Queensland Koala Conservation State Planning Regulatory Provisions (SPRP) and the State Planning Policy 2/10: Koala Conservation (SPP). The South East Queensland Koala Protection Area includes the eastern seven Local Government Areas of South East Queensland (Moreton, Redland, Gold Coast, Sunshine Coast, Brisbane, Ipswich and Logan) (Figure 1).

Figure 1 State Planning Regulatory Provision area, State Planning Policy area and Local Government Area boundaries.

Major efforts were focussed on the Pine Rivers and Koala Coast district because that was where the koala population was demonstrably under the most acute stress and risk of extinction.

The policies are complemented by the State Government Community Infrastructure Policy which requires community infrastructure to achieve a net gain in habitat and incorporate koala sensitive design measures. Providers are required to self-assess their impacts and the

Queensland Department of Environment and Resource Management plays an audit and assessment role.

The SPRP is the pre-eminent state planning instrument with overriding powers over other planning instruments; it prevails in the case of inconsistencies with other planning instruments, plans, policies or codes. The SPRP identifies conservation areas upfront during the development process, and locks those down. Provisions include:

1) Prohibiting urban activities outside urban footprint/zones.
2) Restricting clearing of bushland habitat in priority areas (Koala Coast and Pine Rivers).
3) Requiring offsets and koala safe movement criteria for areas that aren't protected.

For each mature koala habitat tree that is removed, five new trees must be planted, or a payment of $920 made to DERM to fund work on acquisitions and rehabilitation. The offset criterion puts a value on trees. Some stakeholders don't believe in the use of offsets but when you're talking about managing land use conflicts you need a tool with flexibility to reform the landscape.

The SPP sets requirements for delivering a net gain in koala bushland habitat and maintaining the viability of local koala populations. The SPP applies to making and amending Local Government planning schemes (must be consistent with the SPP), structure and master plans, and community infrastructure designations. Its key requirements are:

1) Significant koala habitat values are protected.
2) Use of koala habitat offsets.
3) Connectivity retained and enhance.
4) Koala safety and movement maximised.
5) Koala conservation assessment criteria.

Progress to date (January 2012) includes instituting a monitoring and reporting program to ensure Local Governments meet their requirements under the SPP and will make that information public. The first report is due later this year. Performance is measured against the key performance indicators of the SPP (e.g. amount of habitat protected).

Since the release of the SPP, Logan, Moreton Bay, Sunshine Coast and Gold Coast planning schemes are being developed or reviewed, 21 structure, master and local area plans have been reviewed against the SPP, and 24 community infrastructure designations have been reviewed against the SPP.

Example of the SPP at work

Kinross Road Structure Plan:

Aerial and habitat values maps (Figures 2 and 3) show koala habitat significance. The maps were used in the development of the structure plan map, to ensure there was no loss of bushland habitat, a significant gain in green space, connectivity was maintained (N-S and E-W), and koala sensitive design measures (including dog restrictions) were imposed as part of the final master plan (Figure 4). The structure plan map is like a miniature town plan, and represents a way to try to get more strategic outcomes so that development isn't random and ad-hoc.

The key lessons include:

1) Best to achieve koala conservation at the local government level
    a. Planning schemes are key to koala conservation
    b. Koala conservation is only as good as the planning scheme matrix provided by each Local Government;
2) Local Governments are unique: allow more flexible / alternative approaches to achieve SPP outcomes;
3) Dog mortality most difficult to resolve: councils are best placed to implement and enforce laws;
4) Further research to define gradients in koala habitat and movement corridors: what size/shape is viable for regional landscape planning?

It's important to work out competing land uses and find land that isn't already spoken for as a starting point. Then have the fight on the other things if you need to. But you can waste a lot of time, energy and political capital fighting a battle over a small place that has a strong competing use.

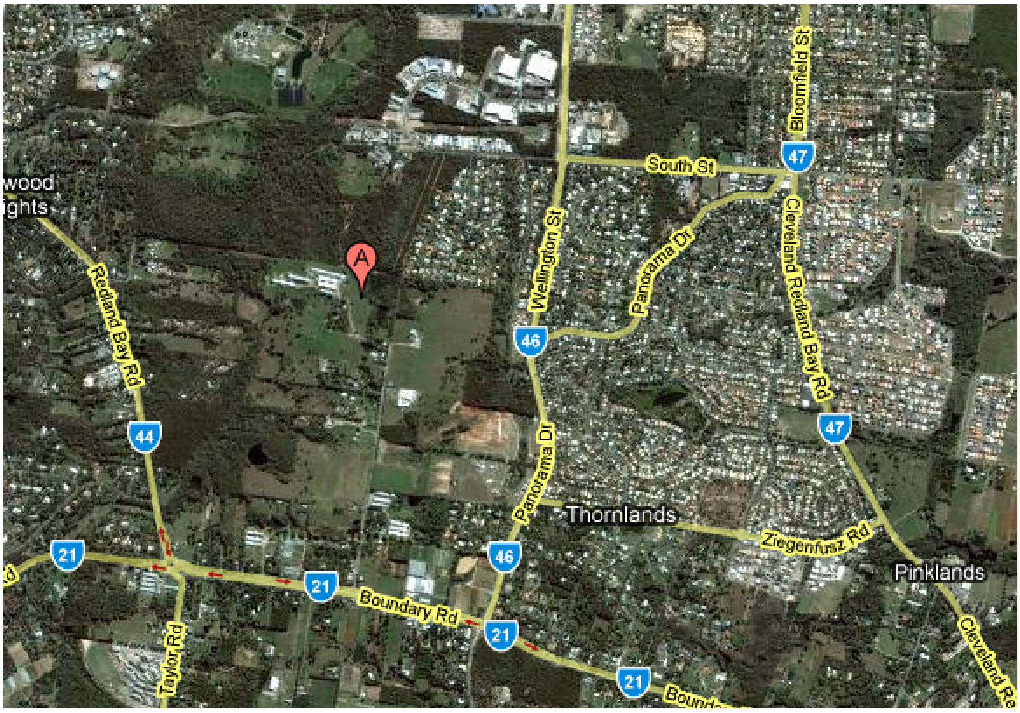

Figure 2 Aerial view of Kinross Road area.

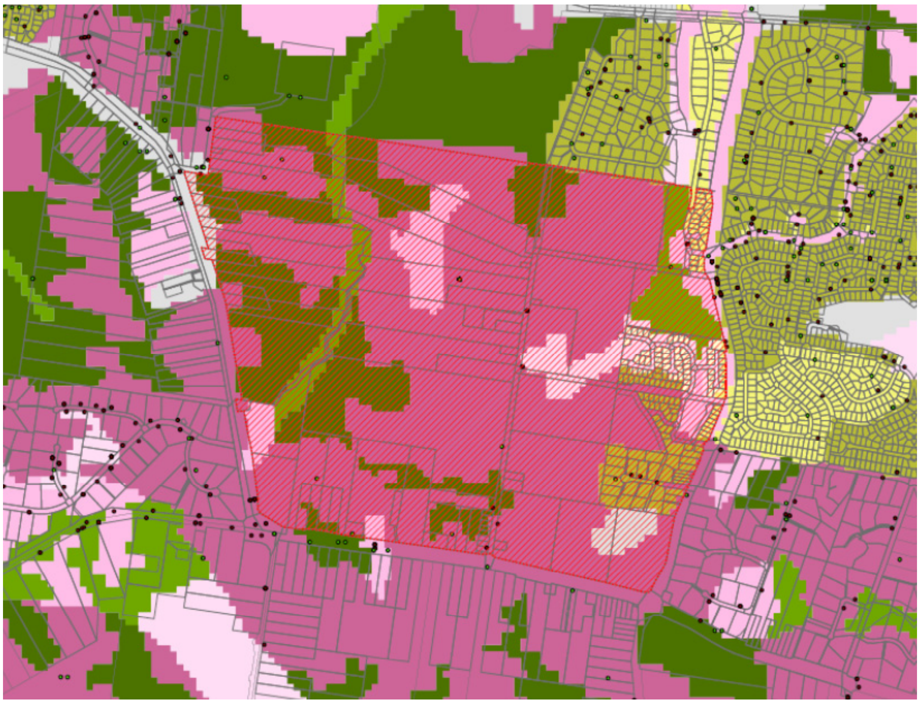

Figure 3 **Habitat values in Kinross Road area (green areas are bushland areas, pink areas are suitable for rehabilitation, there are also rankings within each category – low, medium and high value).**

Figure 4 **Kinross Road Structure Plan (dark green = protected bushland; light green = green scape corridors; pink = residential that will provide habitat street scaping and dog restrictions).**

Koala Land: koala research collaboration project

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Koala Land is a project that consists of a website, report and publication. It is built on the premise that we need to establish the link between the survival of koalas and our own species, and that saving koalas is a shared responsibility. The *Koala Land* website and report can be found at www.koalaland.com.au.

The project establishes that the koala and koala issues should not be treated in isolation. It is worth considering how the koala, and ourselves, fit into the overall picture – the environment.

In particular, the *Koala Land* project considers ways of creating a sustainable future for koalas and people on the Koala Coast, South East Queensland. While the blog component of the website opens up conversations around the broader subject of koalas, the report aims to recommend ways of planning for protecting koalas and koala habitats. By presenting the perfect habitat for koalas, the report establishes and illustrates what is needed to maintain existing koala habitats and rethinks sustainable environments where the human and koala environment can co-exist.

The report is a collection of knowledge, with findings and anecdotes based on conversations with people including Assoc. Prof. Clive McAlpine, Dr Stephen Phillips, John Callaghan, Dr Steve Johnston, Dr William Ellis, Dr Sean FitzGibbon, Dr Darryl Jones, Dr Jean-Marc Hero, Prof. Frank Carrick AM, Debborah Tabbart OAM and Cheyne Flannagan.

The challenge in setting out to create the report was how to translate science and complex information in a clear and direct manner, and how to communicate this to government, people and industry at the same time. Given the broadness of this “all people” audience, the approach has been to take on direct forms of communication – easy to understand explanations of otherwise complex and specialised scientific language complemented by a visual narrative.

By bringing koala behaviour to the forefront of peoples’ consciousness, the report focuses on koala home ranges and the need for koalas to move along the ground as crucial starting points in considering any planning requirements and land uses within and near koala habitats. Looking at the big picture, the report sets out the necessary actions we need to take, from the micro to the macro – backyard and curb side, to the greater landscape and environment as a whole. We have to rethink and design in a way that uses space and resources more intelligently.

As a starting point for rebuilding koala networks, *Koala Land* takes the position that all existing koala habitats must be protected and stabilised. Beyond this, better habitats for humans need to be created (by planning for koala-friendly town centres), new networks of koala habitats and corridors must be rebuilt in both rural and urban environments, and patches of koala habitat that cannot be reconnected will need to be managed as a part of the network (genome banks and translocation).

The way that urban developments currently use land and resources represents an out-of-date agenda that needs to be rethought. While the building industry has challenged the protection of the koala on the basis that Queenslanders will lose jobs, the *Koala Land* project argues that as human populations continue to rise, new town centres can be created if planning is inclusive of the needs of koalas. The building of new infrastructure and dwellings can incorporate the replanting of koala corridors and habitats, which can create more jobs in the long term. We need to plan and build in a more careful and creative manner, enhancing yields by including koalas. “Economies of Better” instead of “Economies of Scale”.

Koala Land proposes that if human populations continue to increase, new building can occur on disused land. These new developments will need to be denser. Denser developments provide more options for affordable housing, more space for community, and more space for koala habitat. Surrounding these minimised urban footprints would be replanted koala habitats and corridors that enhance the overall koala network. Parts of these koala habitats can be multi-use, which might incorporate recreation facilities, bike tracks, walking tracks and communal gardens. To reduce the pressures on the land and our consumption of resources, *Koala Land* suggests approaches like permaculture in these multi-use zones, which could be planned into developments from the outset. New roads that connect community centres can go under and over the land.

In the process of observing how urban developments and resource consumption interfere with and destroy koala habitat, *Koala Land* investigates how the demand for koala-friendly urban developments can exist, and considers how these community-based, self-sufficient town centres can be promoted. This approach has evolved into an online social networking strategy as a means of bringing Generation Y to the koala issue. If Generation Y understands what is happening to koala habitats, and how our current ways of using land and resources affects koalas and koala habitats, then this future generation of home buyers and entrepreneurs will demand environments that respect the needs of koalas and all other native flora and fauna.

We want people to demand better both for ourselves and koalas.

The social networking strategy utilises tools like Facebook (facebook.com/KoalaLand), Twitter (twitter.com/koala_land) and Tumblr, (tumblr.koalaland.com.au). For Generation Y, these virtual spaces are their meeting places and their communities. Our editorial approach is to intentionally publish playful collections of anecdotes and imagery of our national icon, making the point that the koala is iconic and broad in its appeal all around the world, and seducing viewers into the *Koala Land* website and blog at www.koalaland.com.au to learn more about the koala’s situation. From experiencing the stereotypically cute to the ridiculous, people are shocked to learn the koala is in danger. The *Koala Land* network is working and building numbers consistently.

The third component of the *Koala Land* project – the publication, is focused on our responsibility to work together as neighbours and communities to rebuild koala populations, and illustrates the beauty of living together with koalas. The document is aimed at local government, the education system and a demographic that is not using the internet.

There are many challenges that the *Koala Land* report only begins to touch on. While the report establishes fundamental links between soil, trees and koalas – it is our society's habits that remain very difficult to shift. We are so entrenched in the way we produce and consume and work and employ. How do we shift the way we think about money? And how do we link money to carbon storage and oxygen, and the opportunities to store carbon by recreating koala habitats and corridors? It is only when we start to understand this that we can truly say that we can help koalas.

Acknowledgements: supported by Dreamworld Australia.

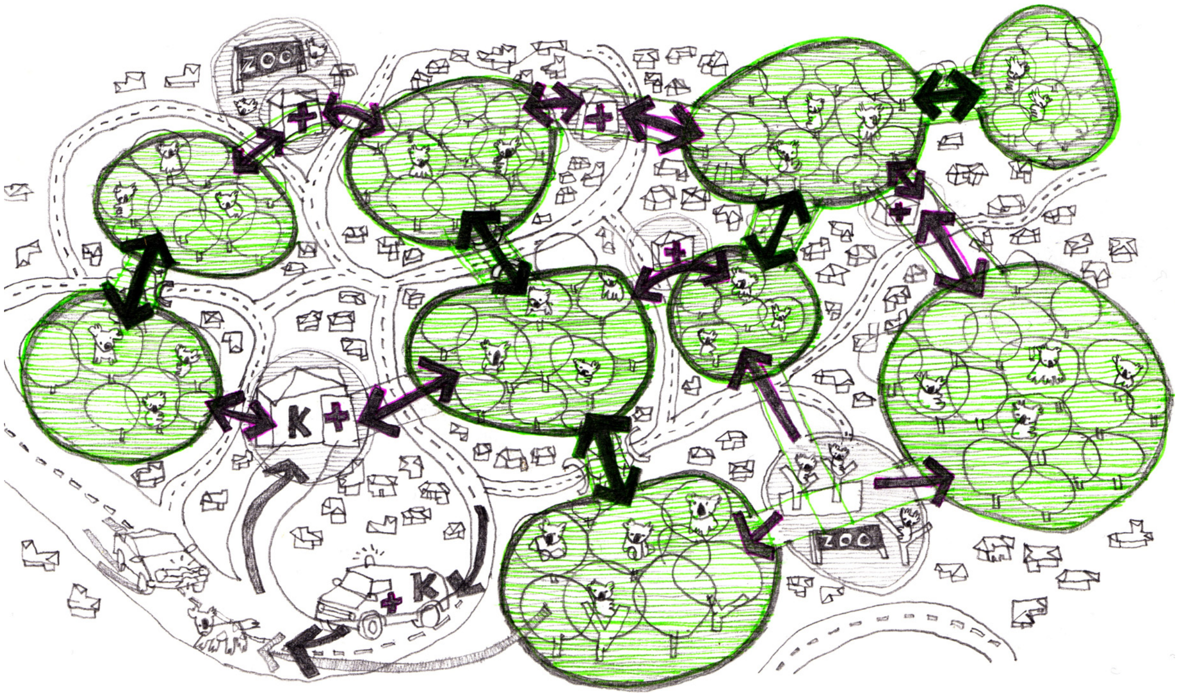

Figure 1 Beyond where koala corridors do not exist and cannot be recreated – zoos, koala hospitals and genome banks will need to ensure connectivity between patches of koala habitat. The *Koala Land* report will communicate the exploration of these concepts and more.

Koalas and climate change: priority koala conservation areas for central Queensland

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Abstract

Rapid global climate change presents a major threat to the world's ecosystems and biodiversity. Australia is no exception, with predictions of hotter temperatures and more climatic variability bringing potentially adverse consequences for its native species and their habitats.

Introduction

The koala (*Phascolarctos cinereus*) has been identified as particularly vulnerable to climate change (IUCN 2009). Furthermore, in arid and semi-arid environments, koala populations were observed to crash during severe droughts when for 12 consecutive days the temperature exceeded 40^{o}C (Gordon et al., 1988). More recently, koala numbers in south west Queensland were found to have declined by 80% (Seabrook et al., 2011). The koala's eucalypt food resources will also be affected by atmospheric concentrations of CO_2 on plant nutritional quality (Hovenden and Williams, 2010) and additionally, a range shift of 73% of Australia's 734 eucalypt species is predicted to occur with a 5^{o}C warming (Hughes et al., 1996). These likely impacts of climate change will compound the existing threats to koalas of habitat loss and fragmentation that are causing population declines in many regions (McAlpine et al., 2006; Rhodes et al., 2008). The major underlying causes of these declines are the clearing of eucalypt forests for the agricultural development of inland regions and continuing growth of the human population along the forested eastern seaboard.

Model development

We developed Maxent species distribution models (Phillips et al., 2004) for the koala and five of its key eucalypt food trees throughout its Australian range to investigate the effects of climate change on their distributions. Underpinning the models was the SRES A1FI high emission climate scenario group that describes a future of rapid economic growth, a global population that peaks in mid-century, and a continuation of high energy needs being met by fossil fuel sources (CSIRO 2011). We chose this scenario because global CO_2 emissions from fossil fuel burning are already tracking near the A1FI scenario (Allison et al., 2009). We used the following variables to develop the models: mean maximum summer temperature and mean annual rainfall (for current and future climate scenarios), distance to water, soil type and elevation. The models were for the koala and: *Eucalyptus camaldulensis* (river red gum), *Eucalyptus coolabah* (coolabah), *Eucalyptus tereticornis* (forest red gum), *Eucalyptus populnea* (poplar box) and *Eucalyptus viminalis* (manna gum). We then calculated the probability of overlap between the koala and the food trees for each climate scenario.

Conservation prioritisation algorithm

Using the same A1FI climate scenarios, we incorporated Maxent models for koalas and their food trees previously developed for Queensland (Adams-Hosking 2011) into Zonation (Moilanen et al., 2005). Zonation is a framework for large-scale conservation planning that produces a hierarchical prioritisation of the landscape based on the conservation value of sites, accounting for complementarity and connectivity.

Results

Maxent models

Predictions for the current climate were reasonably congruent with the current distributions of koalas and the food trees. Distributions for the food trees generally contracted eastwards and often southwards particularly by 2070 and food/habitat therefore became increasingly fragmented (Figure 1).

Central Queensland region

The highest probability of overlap for the koala and coolabah and poplar box occurred in eastern regions, inland from the coast and sometimes in existing protected areas such as Kroombit Tops National Park (Figure 2A, B). The highest probability of overlap for the koala and river red gum occurred in fragmented patches of the region (Figure 2C). For the koala and forest red gum there was a generally low probability of overlap in this region (Figure 2D).

Conservation prioritisation

The Queensland Zonation analysis for this region indicated that as climate change progressed, highest priority areas contracted from western regions towards eastern and coastal areas. Notably, the islands inhabited by koalas on the central Queensland coast, became high priority (top 5-10%) as climate change progressed from 2050-2070 (Figure 3).

When examining how the variables influenced the Australian Maxent models, mean annual rainfall and mean maximum summer temperature contributed the most for koalas and most tree species (Table 1). For river red gum, rainfall (27.5%) and distance to water (39.7%) contributed most to the model, and for coolabah, cracking clay soils contributed the most (25.7%) (Table 1). The discriminative ability of all models was high with only river red gum having a moderate discriminative ability of AUC = 0.713 (no better than random prediction = 0.5). Elevation made a weak contribution to all models (0.4-5.6%) and none of the soils made strong contributions with the exception of cracking clay to coolabah. The probability of presence declined with increasing distance to water in the koala and all food tree models.

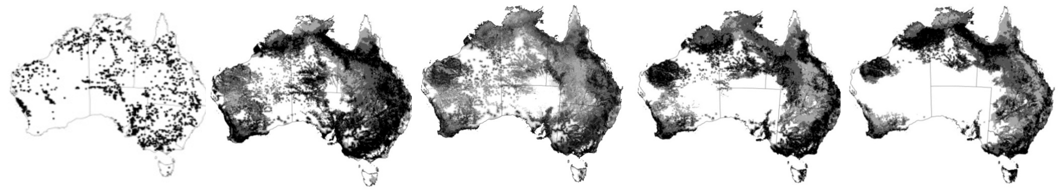
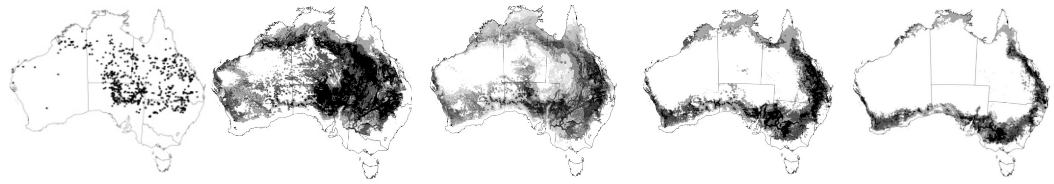
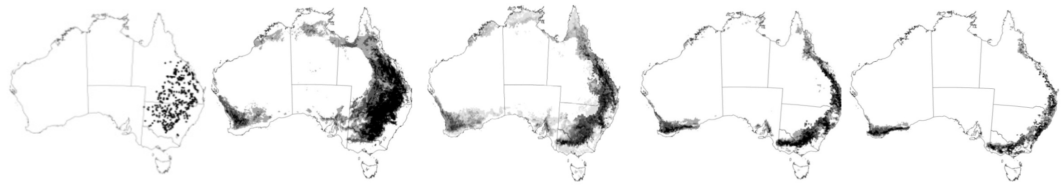
Species	Current distribution	Predicted Current climate	Predicted 2030	Predicted 2050	Predicted 2070
a) Koala					
b) *E.camaldulensis*					
c) *E. coolabah*					
d) *E. populnea*					
e) *E.tereticornis*					
f) *E. viminalis*					

Figure 1 Maxent species distribution models of the koala and the food tree distributions. Black indicates highest probability of occurrence. Source: Adams-Hosking et al., 2012.

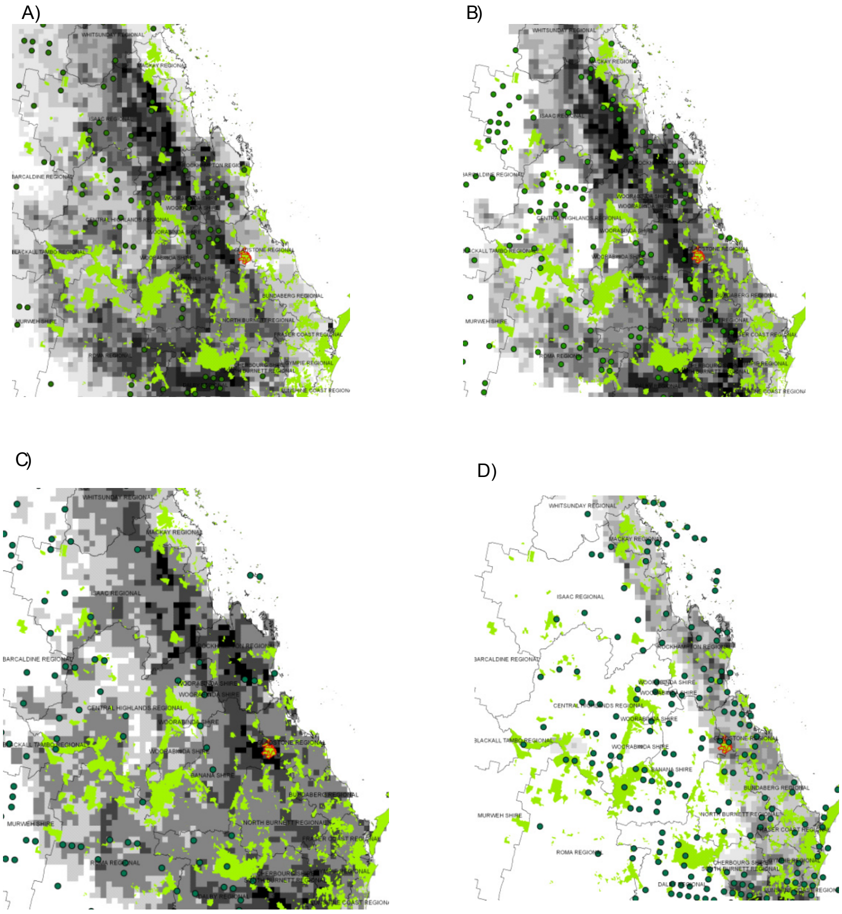


Figure 2 Probabilities of overlap for koalas and A) *E. coolabah, B) E. populnea*), C) *E. camaldulensis* and D) *E. tereticornis* for 2030. Black indicates the highest probability of overlap. Protected areas are shown in green. Red indicates Kroombit Tops National Park. Green circles indicate current records for each respective food tree species. Source: Adams-Hosking et al., 2012*.*

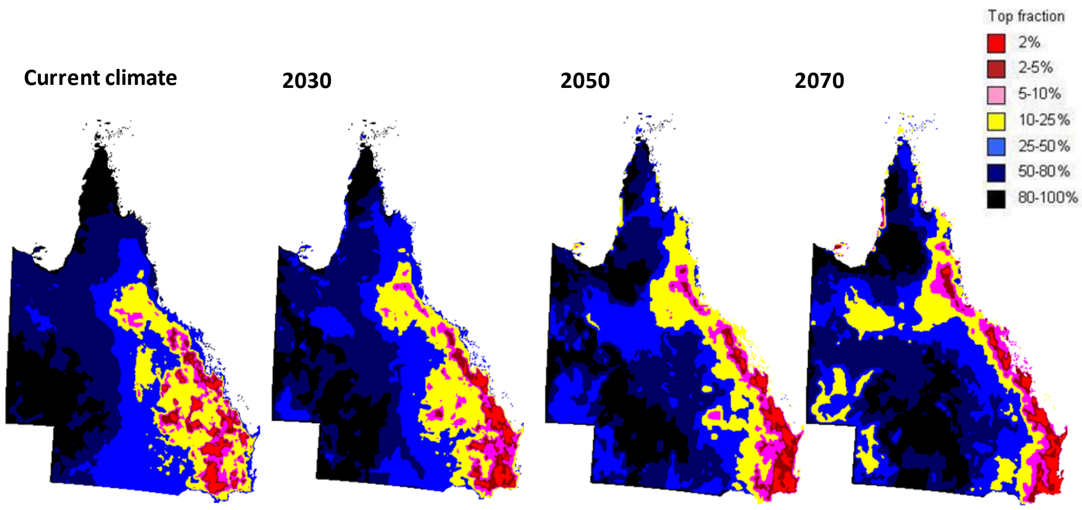


Figure 3 Raw Zonation output maps for Queensland with red areas top priority and black lowest priority areas for koala conservation. Source: Adams-Hosking, 2011.

Discussion: Implications for conservation planning

The geographic range of koalas in the central Queensland region is predicted to contract eastwards as climate change progresses. The distributions of their food trees are predicted to fragment and contract, generally eastwards. Therefore, conservation planning efforts for koalas in this region, as elsewhere, need to also consider the impacts of climate change on their key food and habitat trees. Regionally-specific, scaled down koala conservation plans can be implemented, for example, through local and state government bodies, with probability of overlap models such as those developed here potentially guiding restoration measures in terms of which trees to plant and where, in view of climate change.

The conservation planning decision support tools implemented here sought to identify important areas for retaining habitat quality under future climate change and developing them into potential conservation resources. It did not discriminate between land uses. Therefore, conservation planning investment needs to incorporate both public and private land. For example, high priority areas that occur on farming or mining land will also be the focus of restoration efforts, perhaps in some cases facilitated by financial incentives. Supplementary plantings of appropriate koala food trees can provide connectivity to other high priority areas and existing protected areas such as Kroombit Tops National Park; such regions and the 'koala islands' of central Queensland have the potential to become critical 'climate refugia' for koalas as climate change advances.

We recognise that species distribution models such as those used in this study have limitations. For example, ecological interactions (e.g. predation), the physiology of the koala (e.g. thermoregulation) and the response of this species to future novel environments were not considered. Nonetheless, these models can be interpreted as indicators of climate change vulnerability. Their purpose is to guide and help inform conservation planning decisions.

Table 1 Top two contributing variables to the models. Adapted from: Adams-Hosking et al., 2012

Species	Mean annual rain (%)	Mean max summer temp (%)	Distance to water (%)	Cracking Clay (%)
E. camaldulensis	27.5		39.7	
E. coolabah		23.7		25.7
E. populnea	20.9	47.0		
E. tereticornis	54.2	37.7		
E. viminalis	5.3	93.8		
Koala	48.7	40.8		

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Regional planning for central Queensland koalas: a framework for planning

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Introduction

This paper presents an approach to state-wide planning for Queensland koalas, using landscapes as the basis of strategic planning. We use the central Queensland coast, around Mackay, and the adjacent hinterland as an example. Here there has been widespread clearing. Remnant vegetation and associated koala habitat occurs as a matrix of fragments and linear corridors at various scales. The coast is extensively developed and the urban footprint is expanding. To the west there is intensive extraction of coal. Surrounding these intensively developed areas is a large rural landscape that has been mostly cleared. The coastal and the western plains are separated by a broad region of hills and ranges – mostly supporting remnant vegetation. Overlying these landscapes is a network of road and rail corridors.

The approach

There are four elements to the proposed planning scheme:

1) State-wide classification of:
   - koala regions based on current and anticipated anthropogenic drivers,
   - regional subdivisions based on pre-European ecosystems reclassified and ranked on value as potential koala habitat (as an indication of likely regrowth);
2) Classify the subdivisions in terms of:
   - remnant or non-remnant,
   - rehabilitation/reconstruction potential, and
   - tenure;
3) Ground-truth to confirm classification and ascertain whether non-remnant subdivisions represent anthropogenic koala habitat or have potential for restoration;
4) Condense the classification to integrated management units – where possible founded on conservation reserves.

The central Queensland coast example

Initially the region is classified into broad land use zones (Figure 1). The coastal plain can be described as a peri-urban zone. There is a large mining infrastructure zone in the west. The surrounding area is largely rural. Within the mining envelope there are about 70 active, developing or proposed coal mines, each with a footprint of somewhat more than 1000 ha. The road and rail network form major infrastructure corridors carrying high intensity traffic and also large industrial traffic. Activity on the infrastructure corridors is intensifying; wider roads carrying more equipment, more quickly, as well as duplicated rail corridors to increasingly developed landscapes.

Those three broad zones: coastal, industrial and rural zones have different characteristics and different pressures; they need to be managed separately but in a related and integrated sense. Planners need to think about the characteristics of those zones in terms of koala habitat.

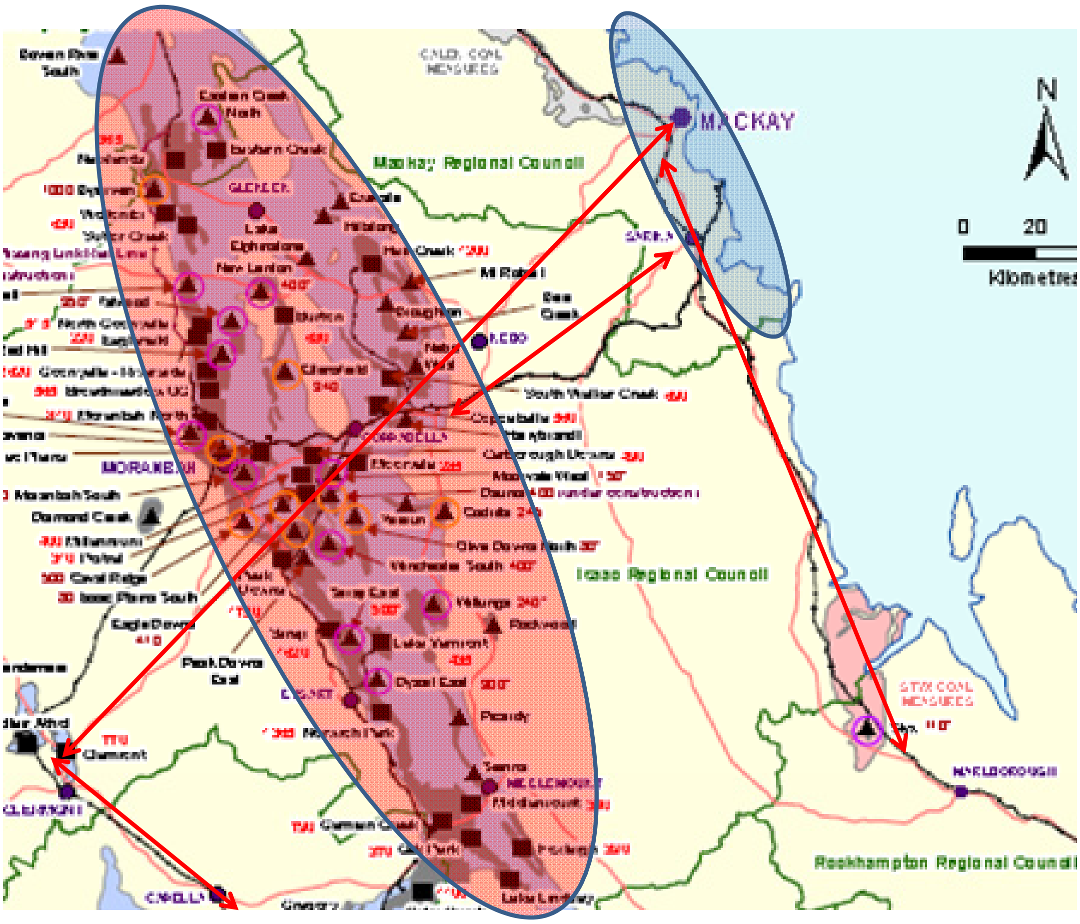

Figure 1 Land use zones in central Queensland (blue zone = coastal and peri-urban, red = resources and infrastructure, remainder is largely rural landscapes).

Coastal and peri-urban zone

In the coastal and peri-urban zone threats to koalas come from dogs, cars, loss of habitat, more roads, more clearing, and more people. Stakeholders include local government, the Queensland Department of Transport and Main Roads (DTMR), QR National, and the Queensland Department of Environment and Resource Management (DERM). In this zone there are opportunities for public awareness and support to address highly visible impacts, which equates to political support for change. The types of responses for koala management in this region are animal and habitat protection, triage, and high value intervention (Table 1).

Table 1 Coastal and peri-urban zone.

Primary stakeholders	Local government, DTMR, QRNational, DERM, urban/peri-urban community, developers.
Key issues	Loss of habitat as development footprint increases, attrition of population by dogs, vehicles, increasing human population density, increasing infrastructure intensity.
Opportunities	Public awareness and support as impacts are highly visible and accessible to large numbers, translates to political support.
Type of responses	Protection, triage, high value intervention.

Resource Zone

Stakeholders in the resource zones and corridors are the resource companies, DTMR, DERM and ports corporations. Major koala issues are loss of habitat, rolling infrastructure and increasing fixed infrastructure along resource corridors. There are great opportunities in this zone as stakeholders have highly regulated environmental management systems and large resource bases. They are experienced in managing large scale physical resources, and have the capacity to resource the community. Types of responses relevant to this zone are strategic broad-acre restoration, rehabilitation as offsets, community facilitation, and resourcing (Table 2).

Table 2 Resources and infrastructure zone.

Primary stakeholders	Resource industries, DTMR, QRNational, DERM, Ports corporations.
Key issues	Loss of habitat as industry footprint increases, attrition of population by vehicles and rail, increasing infrastructure intensity along resource corridors.
Opportunities	Stakeholders have high quality environmental management systems and very large resource base. Experienced in managing large-scale logistics and major projects. Used to managing under a highly regulated environment, existing capacity to resource community needs.
Type of responses	Strategic broad acre restoration and rehabilitation associated with offsets. Community facilitation and resourcing.

Rural Zone

In rural landscapes the stakeholders are property owners, Local Governments, DTMR, QR National, and DERM. Rural land management issues include grazing impacts, financial challenges, logistical constraints, and limited access. The opportunities in this zone are that probably the majority of koalas occur in this zone. There are also community opportunities and the benefits that come from broad acre land custodianship. Responses appropriate to the zone might include incentive programs for koala husbandry (encourage landholders to produce this resource for us as a product), and the maintenance of anthropogenic koala habitat (Table 3).

Table 3 Rural landscapes zone.

Primary stakeholders	Rural landholders, Local government, DTMR, QR National, DERM.
Key issues	Rural land management issues (grazing impacts on forest succession etc), financial challenges, logistical constraints, limited access.
Opportunities	Community, broad-acre land custodianship.
Type of responses	Incentive programs supporting rural koala husbandry, maintenance of anthropogenic koala habitat.

Conclusion

Rural landholders are probably managing the greatest extent of koala habitat in the state. If society values this, then the custodian should be rewarded, not just regulated. The resource sector is subject to environmental regulation, but has the systems, resources and experience to respond to regulations, the mechanisms for contributing to regional communities, and could support rural landholders in their management of koala habitat and reconstruction. Governments could facilitate mining companies to help landowners to manage their landscapes for koalas. Conservation land managers (Queensland Parks and Wildlife Service) need to be able to apply koala sensitive, and habitat sensitive, land management systems to conservation tenures.

This paper presents a conceptually simple approach to koala conservation planning. The tools to pursue this are currently available in both the government and private sectors. The extent and rate of development in the resource sector and peri-urban environment demand a proactive approach to koala conservation planning. There are opportunities for public-private partnerships to fund this approach. The priorities are high and timeframe is limited.

WORKSHOP SESSION 7: Regional planning for conservation alongside resource extraction, urban expansion and rural enterprises

Conservation management is generally not coordinated, usually reactive rather than pre-emptively perusing long term strategies. This is a consequence of statutory regulation applied to individual actions. Further, the current assessment process generally does not measure cumulative impacts of multiple developments. Partly this is due to insufficient engagement by conservation researchers with stakeholders and regulators. Often conservation efforts are seen as competing with local interests (e.g. employment or regional development). However, ecologically sensitive regional planning may become entrenched in planning schemes if benefits to social and economic development are better communicated.

There are opportunities for strategic conservation planning in central Queensland. Unfortunately conservation planning is lagging behind development, and planning for infrastructure and large scale projects make no commitments to conservation goals. Part of the problem is that many projects are being developed under historical commitments (usually exploration and resource development) when conservation impacts were not so well understood.

Timing is important. Planning for resource extraction precedes on-ground work by some years although environmental commitments are rarely incorporated until after operations begin. Further, introducing new ideas, such as changing from localized offsets and discrete rehabilitation targets to a more strategic approach, requires government support and this takes time. Key to developing a regional planning scheme is a database of known and map-able existing development commitments – especially mining and exploration.

The planning processes within each of the proposed land use zones need to be better understood. Where possible, synergy should be sought between potentially overlapping schemes (e.g. strategic cropping lands and strategic koala conservation areas). Further work is required to refine climate impact models to fit different scenarios in each land use zone. Within the mining and resource zone there needs to be some recognition of the potential for mine site rehabilitation to provide koala habitat and some action is required to raise this as a priority.

Within the resource sector there is a need to communicate the benefits of 'koala habitat' as a resource for the community. Further, as few are interested in the environment for esoteric reasons, both rewards and costs need to be available to ensure strategic conservation goals are met. However, many mines in Queensland are behind in their rehabilitation goals. The sense is that there is an increasing gap between disturbed land and rehabilitation progress. This is a challenge for regulators and an opportunity for conservation planners. The mining sector has budgeted for the rehabilitating their degraded sites. The possibility is there to apply resources to meet mine restoration goals and to achieve strategic outcomes for conservation that may involve investing on lands remote from the mine footprint. There is some concern that existing regulation is not effective in achieving conservation outcomes in the face of resource extraction priorities. So a need has arisen to negotiate a regional framework that manages impacts, achieves restoration goals for conservation and pre-emptively avoids conflict despite the limitations in the regulatory framework. There are some examples of mining companies "leading the way" (e.g. Sand mining on North Stradbroke Island. Here land was handed back for national park and the creation of koala habitat).

Within the rural sector the issue now is not the presence of disincentives to destroy habitat but a lack of incentives to restore or manage it. Financial incentives are important but so are non-financial incentives (e.g. longer leases in return for protecting wildlife). It was noted, however, that the state nature refuge program is not effective in the face of pressures for resource extraction. Again pre-emptively identifying strategic land for koalas outside of potential conflict zones is seen as important. Options for managing strategic koala lands included property purchase by non-profit organizations and funded management arrangements with existing landholders. Whatever the approach, it was considered critical to make the right management information available to landholders – but also to share local property knowledge with conservation managers.

Theme 8. RECOVERING KOALA HABITAT

Recovering koala habitat

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The South East Queensland (SEQ) Koala Habitat Protection and Rehabilitation Plan is part of Queensland Government Koala Response Strategy, announced in December 2008. The Queensland Government has committed $50.5 million over six years for koala conservation to halt the decline of SEQ koala populations. $48 million of this is for habitat protection and rehabilitation programs, and $2.5 million for enhanced koala population surveying and monitoring. The strategy includes an objective to achieve a net gain in actively regenerating and mature koala habitat in SEQ by 2020.

The Plan aims to increase koala habitat in SEQ by revegetating cleared and degraded land to restore koala habitat in areas where it has been lost. The Department of Environment and Resource Management (DERM) purchases cleared or partially cleared land that is mapped as having two or more hectares of high or medium value land suitable for rehabilitation as koala habitat (Figure 1).

The aim is to rehabilitate properties and convert them to a secure tenure that will ensure their habitat protection in perpetuity. This might include: protected areas such as National Park or Conservation Park (most protected), Nature Refuge with mandatory habitat protection noted on the Title, or Reserve under the Land Act, managed in trust (by a Local Government for example).

Progress to date

As of January 2012 the project has:

- Established a task-dedicated Habitat Rehabilitation Team of seven rangers
- Purchased eight properties (first mid-2010) with a total property area 380 ha
- Spent $15.67 million on property purchases
- Completed operational works to a value of $530 000
- Replanted 81.8 ha with 31 446 trees
- 29 974 trees remain to be planted.

This is happening in a highly fragmented landscape where people like to live and which is or was prime koala habitat. Property values are high.

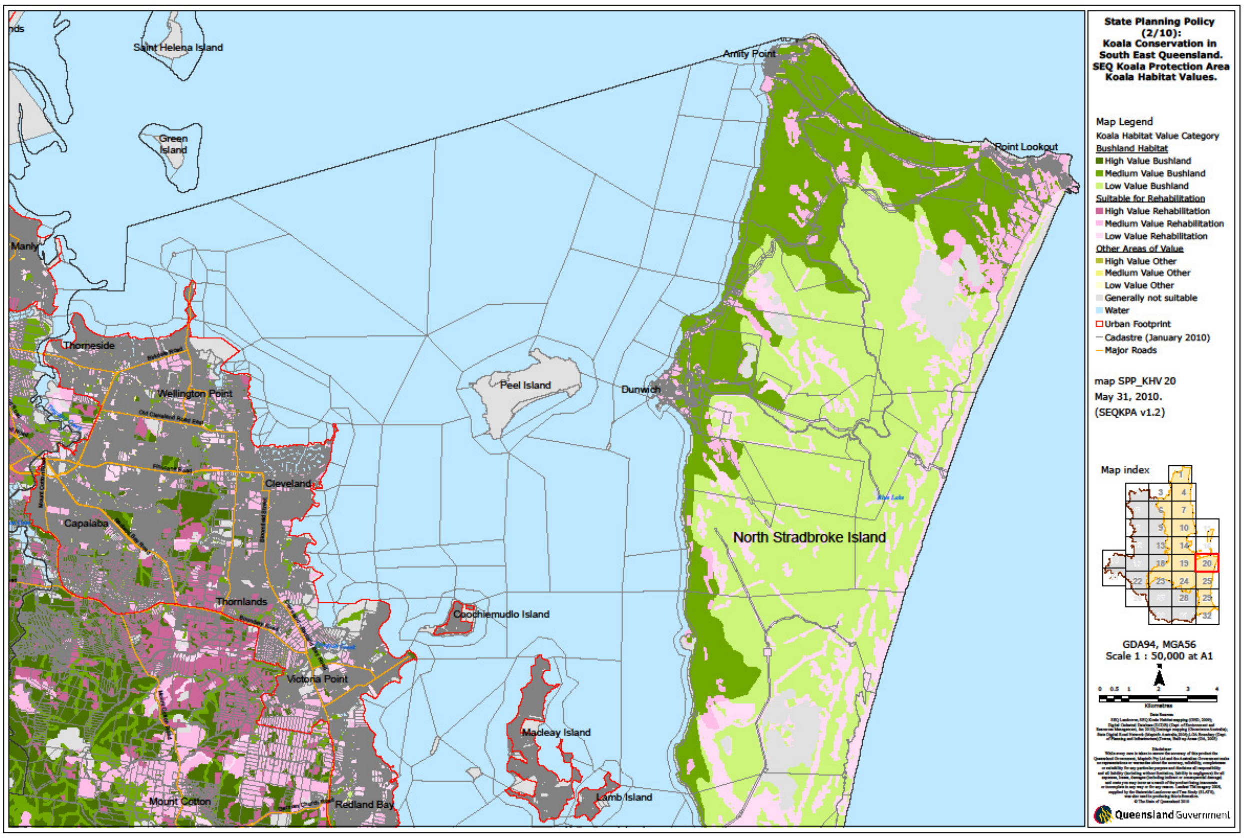

Figure 1 Example of mapped areas of High and Medium Value Suitable for Rehabilitation Habitat (dark pink = high value rehabilitation, mid-pink = medium value rehabilitation).

Lessons learned

- Recovering habitat in an urbanised, developing landscape is very expensive.
  - Land is expensive
  - Ex-working properties (e.g. cattle) require demolition and removal of unwanted infrastructure, which add further expense. Properties may have infrastructure such as houses, sheds, fences, accumulated rubbish, and swimming pools (some of this can be and is reused, e.g. gates, tanks)
  - There may also be stock that require removal
  - Pre-planting weed management is labour-intensive – it is often necessary to get into the thickets of weeds with thrashers.
- Presence of asbestos on older properties is problematic (in fibro, insulation around pipes) – it requires expensive specialised assessment, removal and disposal processes which are legislated. Audits are run on any properties that are purchased. If asbestos if found we have to make a determination about whether or not to remove it.
- Close liaison with neighbours is important to avoid misconceptions – what we are doing, and what they believe they can continue to do (e.g. grazing stock on the land).
- Natural eucalypt regeneration can occur rapidly after removal of grazing pressure.

- It pays to recycle – e.g. we re-use building materials where possible, and scrap metal is sold.
- Maintaining a rehabilitated area (e.g. watering, weeding) is a long term exercise – up to five years.
- Maintenance can be very costly if contractors are used (e.g. $1000 per month for five years on a small block).
- Growth rates of some of our replanting has been more rapid than expected (e.g. Capalaba West – regrowth has reached four metres within two years). The mix of habitat trees we put in is matched as well as possible to the RE of the area.
- Adverse weather conditions can affect planting program – e.g. rain (delay of three months in fire break construction), drought (diminished growth rates).
- Animals also affect planting success – both native and feral animals may dig up and/or eat plants – seedling guards are essential and are regularly maintained.

Myrtle rust is an emerging threat to koala habitat. It has already been detected on two of the rehabilitated properties and infected plants (*Melaleuca quinquenervia*) have been cut down and removed. All properties are now routinely inspected for myrtle rust during general progress inspections. It’s unstoppable, it’s out in the landscape and all we can do is try to minimise the impact. The disease has the potential to bring the rehabilitation program to a halt. [*Note (D.B.) If you have seen or suspect symptoms of myrtle rust contact Biosecurity Queensland by calling 13 25 23 or visiting* www.biosecurity.queensland.gov.au.]

The Koala Venture Partnership: Habitat clearing and restoration

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The aim of the Koala Venture Research Partnership is to enhance koala management and conservation through improved scientific understanding of koala movement, density, home range size, habitat preferences, breeding, growth, longevity, dietary preferences, disease types and expression, response to vegetation clearance, and use of rehabilitated areas (See FitzGibbon et al. page 16 this volume). At Blair Athol Coal Mine there have already been efforts to rehabilitate cleared land, while at Clermont Coal Mine land is still being cleared for mining.

Use of rehabilitated and regrowth land at Blair Athol Mine

“Bullseye” was an adult male koala tracked at Blair Athol Coal Mine. His movements are shown in Figure 1. One movement made by “Bullseye” encompassed some rehabilitated area, and represents the first firm evidence that koalas will use rehabilitated land after coal mining. The area illustrated on the left hand side of the photograph (circled in orange) was cleared in 1985 but was not ever mined, and has now naturally regrown. The area circled in red in the same figure was mined for coal and then rehabilitated in 1996; this included replacing a thin layer of topsoil and planting tree tube-stock. Unfortunately, a lot of that 1996 rehabilitated habitat has been recently cleared to access a deeper coal seam.

But prior to the recent clearing, the 1996 rehabilitated area was well developed and offered good quality habitat to koalas. The trees were a good species mix, not all were native to the area but there were plenty of known koala food trees such as narrow-leaved iron bark. “Bullseye” was found using the area 12 years after planting but it is likely that he or other koalas may have utilised the area prior to our recorded use. Therefore, it is suggested that koala habitat in this area of central Queensland can be restored within a 10-12 year timeframe, under reasonable environmental conditions. Of course, this timeframe may be significantly reduced in less disturbed soil profiles such as on nearby grazing and cropping land.

“Hillary” was a little adult female koala who moved quickly into the rehabilitated area after being captured outside of it, and stayed there for a year (Figure 2). The rehabilitated area was good enough for her to stay entirely within it for a whole year and she conceived a young while living there. “Hillary” later used an adjacent area that was rehabilitated in 1999 which contained smaller and sparser trees (see Figure 3).

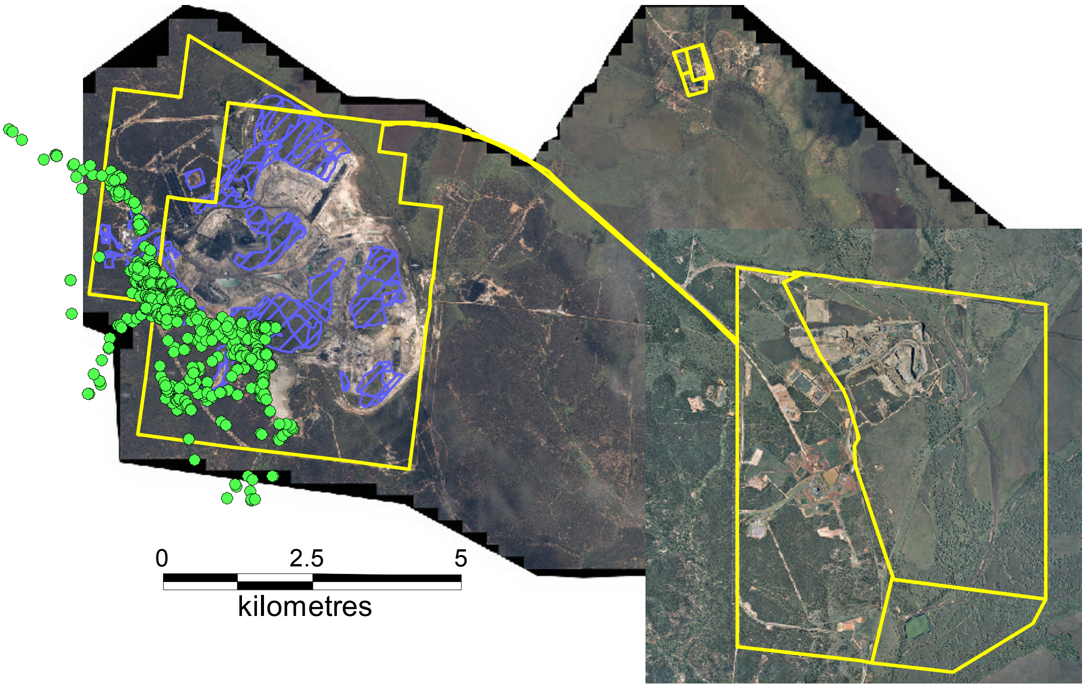

Figure 1 **Bulleye's home range at Blair Athol Mine, including rehabilitated areas (blue hatched).**

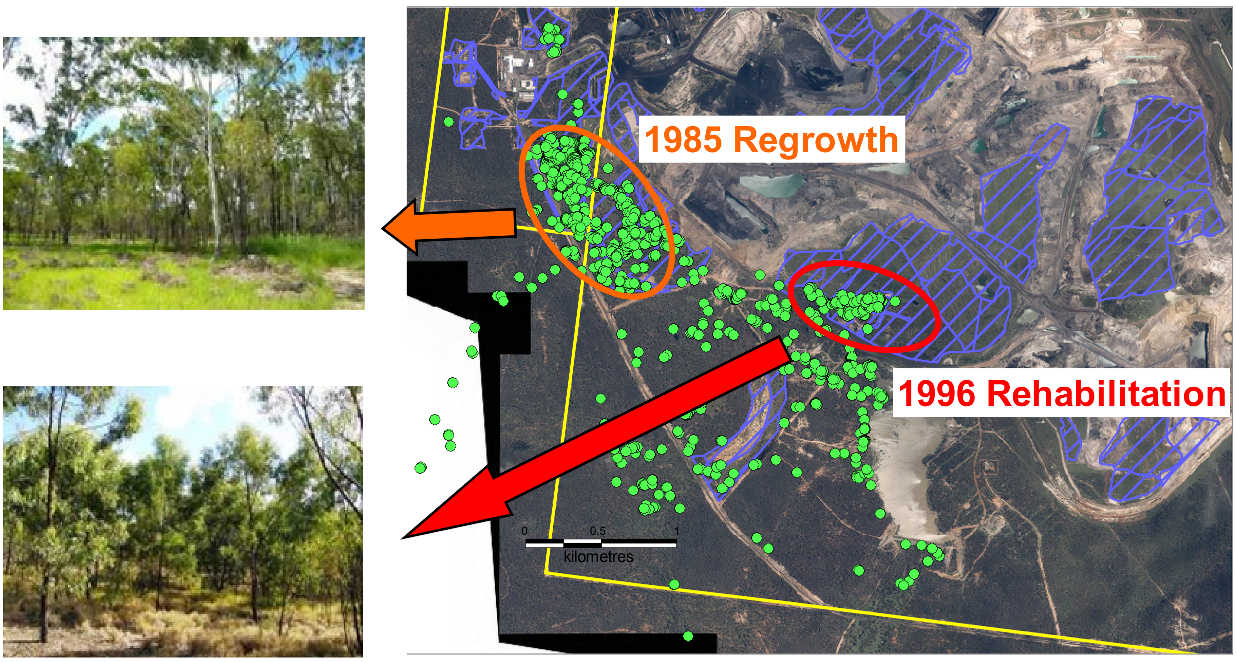

Figure 2 **Bullseye's movements including into 1985 regrowth forest and 1996 rehabilitated forest.**

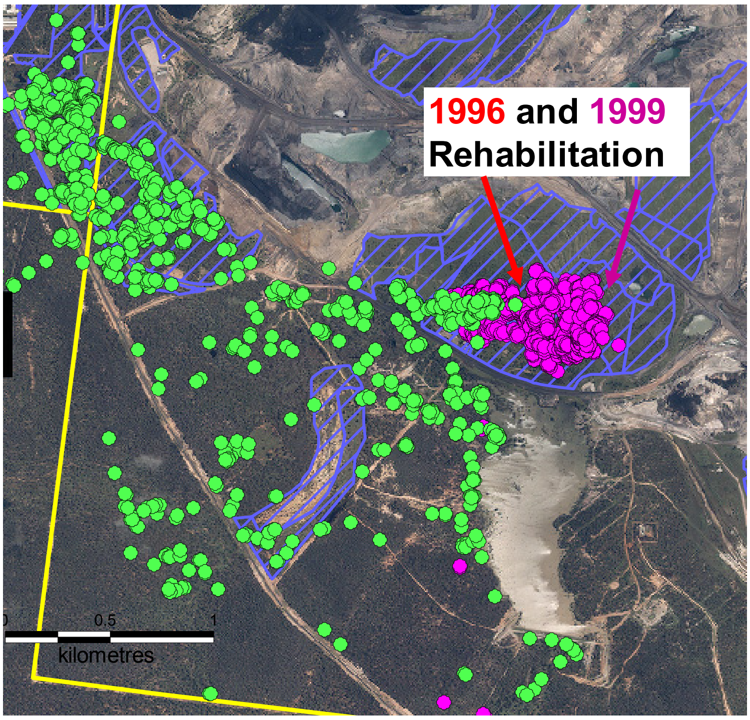

Figure 3 Hillary's movements (pink dots) in rehabilitated forest at Blair Athol Mine (1996 and 1999 rehabilitation areas).

To further examine koala use of areas of Blair Athol Mine we conducted a search of 26 rehabilitated and regrown sites on the mine, ranging from 11 to 27 years old. 20 of the sites were rehabilitated (i.e. had been mined for coal) and six were regrowth (i.e. had been cleared but never mined). Scat surveys were conducted along transects. We found that 10% of rehabilitated sites (two of the 20) had been utilised by koalas (these were the same two sites that Hillary used); two of the six regrowth sites had also been utilised by koalas (33%). The major drivers for use of rehabilitated and regrowth sites are likely to be proximity to source forest and habitat quality (tree species, height and girth). This emphasises the need to maintain a good connection with existing forest as well as re-establishing good quality habitat.

Managing koalas during vegetation clearance at Clermont Coal Mine

There are no existing published studies about managing koala populations during land clearing. We tried to do this at Clermont Coal Mine when a large area of coolabah woodland needed to be cleared for the establishment of the mine. It provided a rare opportunity to use our understanding of koala movement to facilitate clearance with minimal impact. We developed a clearing strategy with the environmental officers at the mine and contracted a spotter-catcher for the project. Koalas were monitored for 12-18 months prior to the event where we attempted to catch and collar every animal spotted in the area to be cleared. After the clearing event monitoring continued to evaluate the clearing strategy and the response of the collared koalas.

The area to be cleared was referred to as the 'northern coolabah woodlands' and comprised a linear corridor 500 m wide and 3.2 km long. The strategy for clearing to minimise negative impacts on koalas was to find each collared koala each morning before clearing. Occupied trees were flagged and left untouched by clearing machinery. The spotter walked in front of the dozer looking for additional uncollared koalas, and these trees were also left untouched. Clearing proceeded from north to south to try and drive the koalas into the large tract of remaining bushland. The dozer cleared around occupied trees but some shrubs were strategically retained as ‘stepping stones’ to the southern woodland. The koalas were left to move overnight of their own volition. Once koalas exited trees the remaining trees were cleared, and collared koalas were monitored closely throughout the exercise. Twelve adult koalas were collared during the pre-clearing phase – they had linear, overlapping home ranges and appeared to be a healthy population (Figure 4).

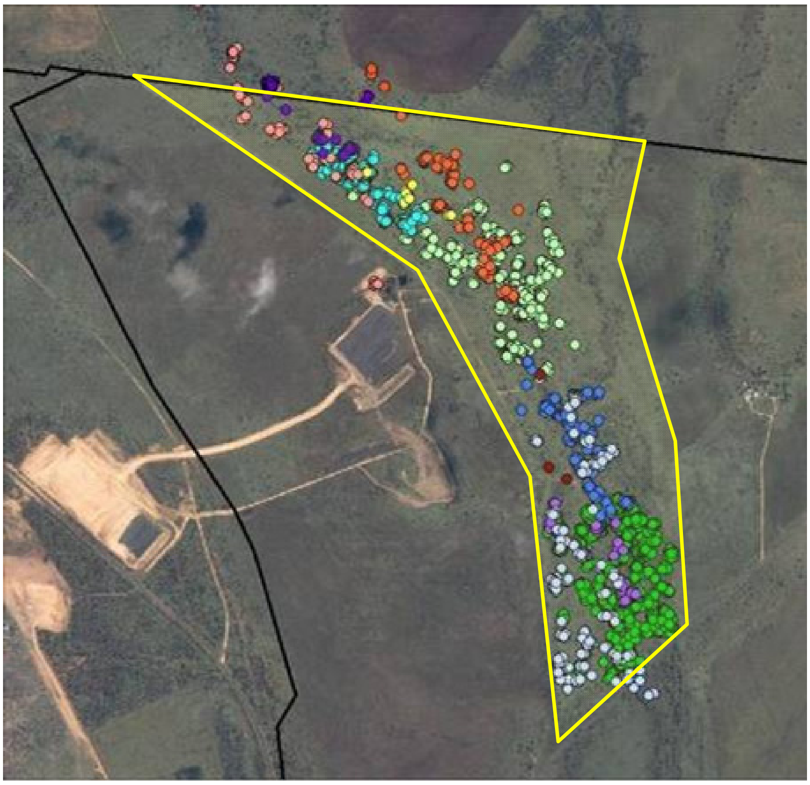

Figure 4 Area to be cleared at Clermont Coal Mine (yellow polygon; approx. 500 m x 3.2 km), and home ranges of 12 collared koalas within the area prior to clearing.

Evaluation of clearing strategy

Clearing was conducted over a relatively short timeframe with the bulk of the clearing occurring within four weeks. The strategy was successful in that there were no direct koala deaths or injuries as a result of clearing i.e. no occupied trees were felled and no koalas were knocked out of trees (we suggest these events were previously rarely avoided in similar circumstances). Most of the koalas responded in the manner we had hoped by exiting occupied trees and moving south towards the large tract of remaining woodland.

The “stepping stone” shrubs and trees were probably beneficial to koalas although we did not attempt to watch the koalas at night to see if they made direct use of these. Unfortunately some of the koalas died soon after the clearing occurred (within 2-4 weeks) and this may have been related to the stress placed upon them during the clearing event. The involvement of a trained and experienced spotter/catcher was considered crucial, especially one who commanded the respect of the dozer driver and crew, and stood firm to protect koalas. Daily tracking of collared koalas allowed confirmation of koala locations making the job easier for the spotter and safer for koalas. Overall, we suggest that the clearing proceeded too fast and that a longer time-frame for clearing would reduce indirect negative impacts such as stress-related immunosuppression. It is suggested that a more effective approach would be to stage the clearing over many months (e.g. <2 ha/wk). A new clearing strategy called “Phased Resource Reduction” is proposed.

Phased Resource Reduction

This would involve:

- identifying the area to be cleared well in advance (12-24 months ahead),
- ring-barking a proportion (e.g. 50-75%) of all food trees to reduce resources,
- allowing ring-barked trees to defoliate,
- monitoring the response of koalas (preferably collared),
- if koalas are still resident, continue ring-barking food trees,
- allow trees to defoliate and continue monitoring koalas, and
- manage adaptively (i.e. by adjusting to the response of the koalas).

The gradual reduction of food resources is likely to mirror drought impacts while maintaining the physical structure of the environment (this is important to allow koalas to escape ground predators such as wild dogs). We hypothesise this clearing strategy will facilitate safe and voluntary movement of koalas into adjacent available forest and avoid indirect deaths.

Clermont is a relatively new mine but they are already undertaking early rehabilitation works. In one area they’ve diverted a creek and cleared the creek line. The new creek line runs through a big bare grassy habitat in what was previously cropping land. This was seen as a good place to start revegetating with local trees to link up habitat to the north and south. In early 2011, several hundred seedling coolabahs were planted in three treatment groups: 1) water tube tree guards that drip water for two weeks, 2) with standard tree guards, and 3) without tree guards. Overall, the plantings have been extremely successful with an average survival of 92% across the treatments after 5-8 months. There was no significant difference in early survivorship between the two types of tree guards (presumably because of the good rain following the planting period) but trees planted without tree guards had reduced survival (71%).

Acknowledgements: UQ staff, RTCA staff, people of Clermont, koalas of the region, photographers.

Restoring riparian koala habitat – Springsure Queensland

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Introduction

There has been extensive dieback in riparian Queensland blue gum (*Eucalyptus tereticornis*) in the Springsure region (Figure 1). The project aims to develop methods for restoring Queensland blue gum, which is a keystone species in the region. The main challenge for revegetation in this landscape is that there will be little or no post-planting maintenance.

Natural recovery is unlikely as the die back of riparian forest opened the canopy and released rapid understorey growth. Generally, tall, dense riparian ground cover precludes germination and smothers seedlings, and under these conditions only rare events produce the open soils necessary for germination and also maintain low ground cover to allow establishment and growth of Queensland blue gum. On cattle properties, grazing suppresses Queensland blue gum saplings and eliminates seedlings. It is likely that natural regeneration would occur rarely and so active restoration is required. Occasionally a suitable event does occur creating the correct conditions for germination, for example drain maintenance in one small area cleared the understorey and allowed germination (Figure 2).

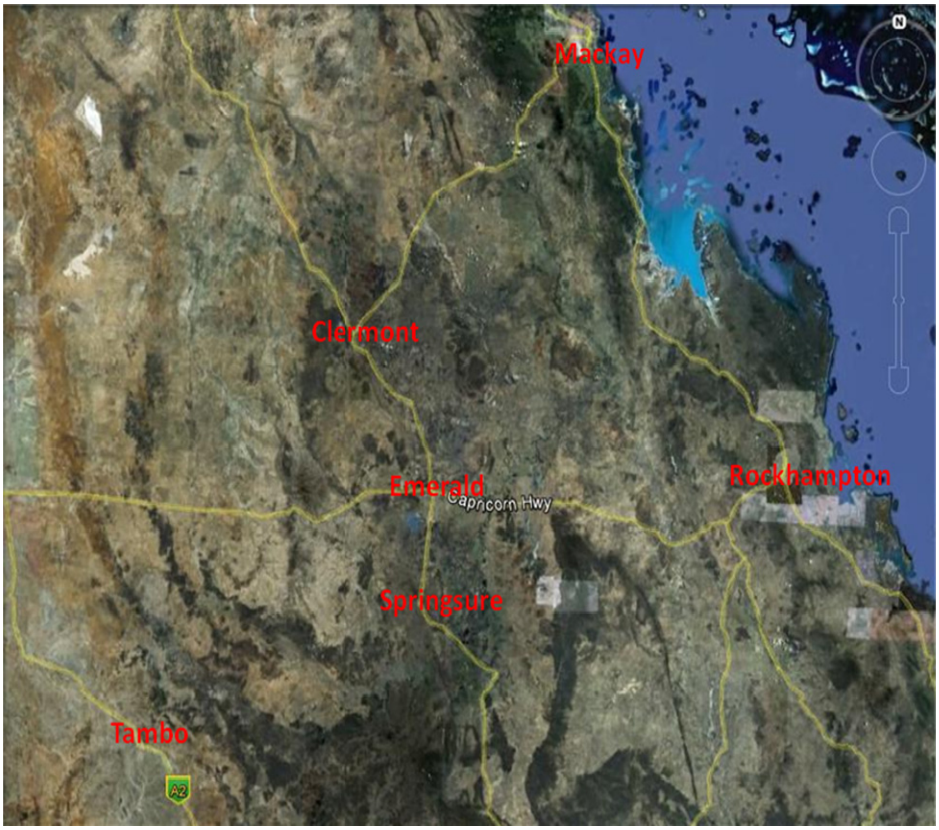

Figure 1 Location of Springsure, Queensland.

Figure 2 Clearing of a storm drain created a suitable germination bed for Queensland blue gum in dense tussock grassy ground cover.

Planting trials

Planting trials have been established under two contrasting land management regimes - Minerva Hills National Park and Norwood Creek Water Reserve – but on the same drainage system. In Minerva Hills National Park, more than 2000 plantings resulted in only 0.003% survival. Threats to planting survival in the national park include grazing by swamp wallabies and rabbits and uprooting by feral pigs as well as overgrowth, and floods (Figure 3).

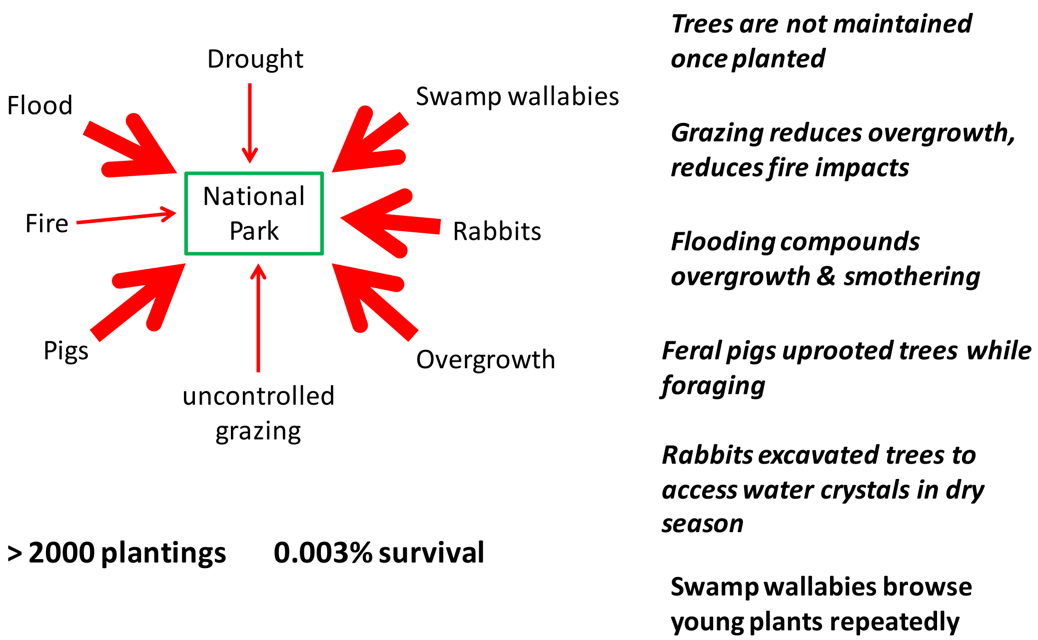

Figure 3 Minerva Hills National Park – factors affecting survival of tree plantings.

Outside of the national park feral animals were not an issue. There were no pigs and few rabbits, and there were few swamp wallabies. Managed grazing was not an issue. The grazing regime was pulsed grazing that reduced the grass load but did not result in extensive browsing of eucalypts. Also fire was not an issue as managed grazing reduced fuel loads and firebreaks reduce the risk of incursion. However, overgrowth by tall tussock grasses, groundwater salting (after rains) and floods remain issues affecting survival of plantings. Despite all that, 2000 plantings had a 0.1% survival rate at Norwood Creek Water Reserve (Figure 4).

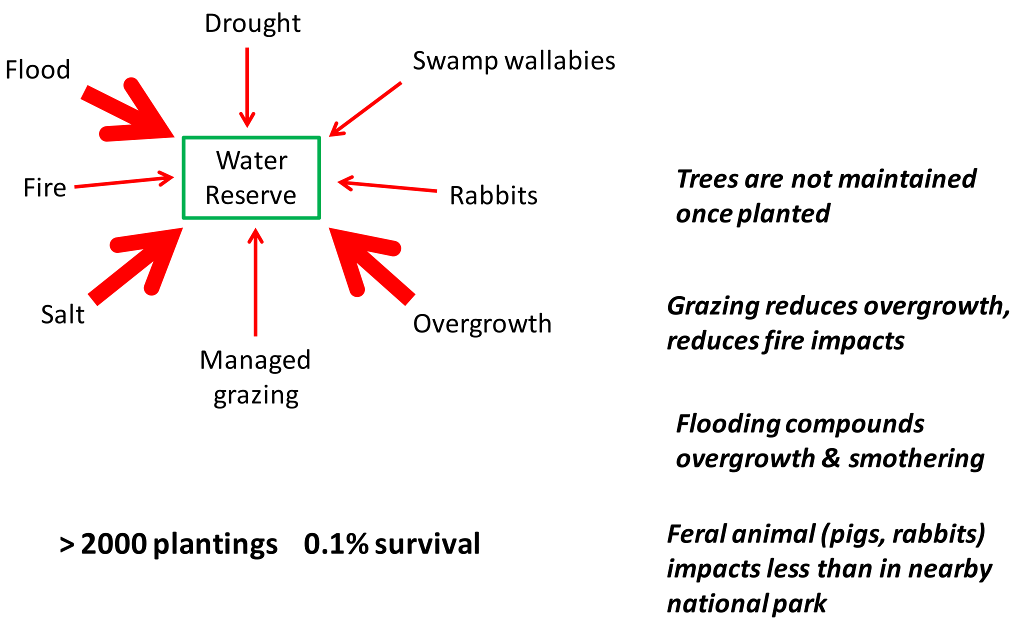

Figure 4 Norwood Creek Water Reserve – factors affecting survival of tree plantings.

Key Lessons

- Tree guards were found to smother and "stew" more trees than they protected. Their use was discontinued.
- Water crystals attracted rabbits in the dry season. The use of water crystals was discontinued and the planting was shifted to a more mesic season.
- Feral pigs uproot plantings, and swamp wallabies browse on small trees. We have trialled fenced exclosures to keep out pigs and swamp wallabies. Advanced tree stock was used in the hope that the foliage would be beyond the reach of swamp wallabies.
- Overgrowth and smothering by tall riparian or exotic grasses. Pulsed grazing has been effective in reducing grass cover. Also, the use of mature planting stock (stems 1 – 1.5 m tall) has effectively avoided the smothering of the grassy understorey.

Discussion

In the national park the compounding effects of pigs, swamp wallabies and unmanaged grazing caused plantings to have a very low survival rates, whereas in the water reserve plantings were much more effective. Because the objective was to re-establish but not maintain plantings the program overplanted in expectation of a high mortality rate. High stocking densities were used, of around 1000 trees in a small area. Eighty-nine of those 1000 trees have survived. Significantly overplanting allowed enough trees to survive to replace those lost to the landscape through drought.

The project also looked at the old terraces to plant silver leafed ironbark (*E. melanophloia*) woodland that's been lost through historical land use in the water reserve. There was an old stock camp in the area with consequent erosion. The ground was hard and gravely but planting survival rate has been about 70% (up until the last flood) after planting directly, watering a week, then returning a year later.

Small exclosures have being trialled to keep out pigs and most of the wallabies. To accelerate growth of plants beyond the reach of swamp wallabies the project has moved from planting seedlings to advanced plants. This is significantly more expensive at $35 per plant as opposed to $1 per seedling, but far fewer plants are needed.

In the water reserve, used for agisting stock, the cattle have not browsed any seedlings. The impacts from cattle have been accidental trampling. However in a commercial grazing property the expectation is that Queensland blue gum saplings and seedlings would be impacted during the seasonal dry when fodder is of low abundance and quality. Consequently it is expected that under these circumstances some exclusion fencing would be needed.

Funded by: Xstrata Coal Corporate Social Involvement Program.

Community partners include: Central Highlands Regional Council (Springsure), Central Queensland Koala Volunteers, Conservation Volunteers Australia, Queensland Parks and Wildlife Service, participating property owners.

WORKSHOP SESSION 8: Restoring koala habitat and scenarios for population recovery

There is potential to restore koala habitat in eastern Australia and reverse the trend of declining range. The extensive 20th C land-clearing has left huge tracts of land for restoration – particularly in rural landscapes where large gains may be made by working with sympathetic landholders/managers or acquiring previously forested land for restoration purposes. Restoration can also be undertaken in urban landscapes (e.g. south east Queensland) but competing land uses make it expensive and less viable.

Broad-scale restoration success requires working with local governments and major stakeholders, e.g. graziers holding significant habitat areas. Getting stakeholders on side may be achieved by an incentives-based nature refuge program offering title over the land in exchange for benefits to landholder e.g. rates reductions. However, under current legislation nature refuges are not protected from mining (e.g. the contested central Queensland Bimblebox Nature Refuge). This vulnerability of nature refuges to the mining act is a disincentive and, if overcome, many more landholders may consider entering into a covenant to protect their land from mining – with biodiversity winning in the process. Many factors apply when planning habitat restoration. The timeframe for restoration will differ across landscapes and over time. For example, grazed areas may contain fertile soils while mined areas will have poor soil profiles with little fertile topsoil. Further, rehabilitation will be most effective in wet years - especially pertinent for inland areas where annual rainfall is highly variable (*make hay while the sun shines!*). The most effective approach to planting (e.g. tube stock *vs* direct seeding) will depend upon issues such as the size of the restoration area, desired tree density and germination success/seedling survival, the labour-force and budget available as well as the prevailing environmental conditions. Seed banks on some grazing lands could germinate naturally under favourable conditions. Grazing stock and restoring/maintaining koala habitat are not mutually exclusive activities; cattle and koalas can coexist (although stock may need to be removed while restoration seedlings reach a robust size). Lastly, the role of fire needs to be considered often providing a cost-effective method of promoting habitat restoration at certain sites.

Climate change models suggest that the range of some koala food tree species will retract towards the coast. This raises the question of whether to restore areas to previous habitat types or to those projected. However, in central Queensland many fodder species are considered to be drought-adapted and there is potential for further adaptation to future change.

Mine rehabilitation raises several important issues. Firstly, is it realistic to regrow the original habitat types after mining given the novel soil profiles and microorganisms? Is it better for mining companies to restore other cleared yet more suitable areas? If so, these could be more strategically located than post-mining land may allow (e.g. connecting creek lines or fragments where koalas occur). Some mines have demonstrated that they can restore koala habitat e.g. at Blair Athol Mine near Clermont, koalas have been found utilising rehabilitated land 12 years after it was mined. However, many miners appear behind on their rehabilitation and there is a tendency to leave restoration until near mine closure. At that point a mine usually has less cash flow and willingness to invest in rehabilitation. So, do state mine regulators need to better enforce progressive rehabilitation? - especially as the state inherits the environmental risk and responsibility after mine closure.

In 2011 the Queensland Government established the ‘Koala Nature Refuges Program’ encouraging koala conservation and habitat rehabilitation on south east Queensland private lands. Under this program “funding is available to select landholders that are willing to revegetate suitable koala habitat and to have part or all of their land declared as a perpetual nature refuge” (*taken from the Koala Nature Refuges Program brochure available online*). Landholders must meet certain criteria e.g. above threshold property size and in suitable location. The Government also has funds available to “purchase from private landholders, at a fair market price, suitable properties identified…as being of ‘high’ or ‘medium value suitability for rehabilitation’ as koala habitat” (*taken from the Koala Nature Refuges Program brochure available online*). Purchased properties were rehabilitated and protected. The Koala Nature Refuges Program is encouraging and the Queensland Government could consider expanding it to other areas of the state through collaboration with local and possibly the federal governments. The approach in rural areas would need to be far more strategic and planned. For example, it would need to consider future land uses (e.g. mining) and possible impacts of climate change. In more rural LGAs such a restoration program may encounter serious feasibility issues e.g. scale – given the much larger areas of land available for restoration – and resourcing suitably sized workforces. But there may also be creative solutions to such problems. For example, some ‘community nurseries’ may be very willing to support rural restoration projects (e.g. provide greenhouse space, grow tubestock) even if they are occurring outside of their LGA. Workforces could be obtained through existing local council programs and community groups. Catchment authorities can be excellent focus points for collaboration with like-minded groups, including Landcare and the Fitzroy Basin Association (a community-based organisation).