NATIONAL KOALA DISEASE RISK ANALYSIS REPORT

Version 1.2 - May 2023

THE UNIVERSITY OF SYDNEY

KOALA HEALTH HUB

Wildlife Health AUSTRALIA

IUCN SSC Species Survival Commission CONSERVATION PLANNING SPECIALIST GROUP Changing the Future for Wildlife

Acknowledgments

The authors acknowledge the Traditional Owners of Country throughout Australia and their continuing connection to land, sea and community. We pay our respects to them and their cultures and to their elders past, present and emerging.

This project is supported by the Australian Government.

Sincere thanks to the many experts who generously donated their time, skills and expertise to the support of this project through participation in workshops and meetings, review of content, provision of documents and sharing of data and personal experiences. We thank you and hope you consider the resulting work to be worthy of your efforts.

We particularly acknowledge the following people for their valuable contribution:

Alison Wright	Dept for Environment and Water, SA
Alistair Legione	University of Melbourne
Alex Greenwood	Leibniz Institute for Zoo and Wildlife Research, Berlin
Amanda Barbosa	Murdoch University
Amber Gillett	Australia Zoo Wildlife Hospital
Andrea Casteriano	University of Sydney
Andrew Hoskins	National Koala Monitoring Program, CSIRO
Belinda Wright	University of Sydney
Bree Talbot	Byron Bay Wildlife Hospital
Cameron Costello	Indigenous representative, Qld
Caroline Marschner	University of Sydney
Carolyn Hogg	University of Sydney
Cheyne Flanagan	Port Macquarie Koala Hospital
Cheryl Sangster	Wildlife pathologist
Chiara Palmieri	University of Queensland
Claire Harrison	Dept of Primary Industries, NSW
Clare Death	Wildlife Health Australia
David Phalen	University of Sydney
Deborah Tabart	Australian Koala Foundation
Damien Higgins	University of Sydney
Denis Rose	Indigenous representative, Vic
Desley Whisson	Deakin University
Emma Hickingbotham	Dept of Environment, Land, Water and Planning, Vic
Gayle McEwen	Leibniz Institute for Zoo and Wildlife Research, Berlin
Ian Hough	Koala Life (formerly Intl Koala Centre of Excellence), SA
Ivan Lawler	Dept of Climate Change, Energy, the Environment & Water, Aust
Jessica Hagan	University of Sydney
Jo Loader	Endeavour Veterinary Ecology, Qld

Joanne Devlin	University of Melbourne
Joanna Griffith	Wildlife veterinarian, SA
Jon Hanger	Endeavour Veterinary Ecology, Qld
Karrie Rose	Australian Registry of Wildlife Health
Katherine Adriaanse	Melbourne Zoo
Keren Cox-Witton	Wildlife Health Australia
Kira Mileham	IUCN Species Survival Commission
Larry Vogelnest	Taronga Zoo
Leanne Wicker	Zoos Victoria
Mark Krockenberger	University of Sydney
Martina Jelocnik	University of the Sunshine Coast
Mathew Crowther	University of Sydney
Meg Curnick	Melbourne Zoo
Michael Pyne	Currumbin Wildlife Sanctuary
Michaela Blyton	University of Queensland
Michelle Campbell-Ward	Australian & New Zealand College of Veterinary Scientists
Mish Simpson	Southern Koala & Echidna Rescue, SA
Natasha Speight	University of Adelaide
Nicole Gallahar	Dept of Planning, Industry & Environment (NSW)
Nicole Marin	International Fund for Animal Welfare
Pam Whiteley	University of Melbourne
Paola Vaz	University of Melbourne
Peter Holz	University of Sydney
Prishani Vengetas	World Wildlife Fund
Rachel Tarlinton	University of Nottingham
Rob Porter	National Landcare Australia
Romane Cristescu	University of the Sunshine Coast
Rupert Woods	Wildlife Health Australia
Sarah Bloustein	Dept of Climate Change, Energy, the Environment & Water, Aust
Sarah Frith	Melbourne Zoo
Scott Carver	University of Tasmania
Stephanie Shaw	Dept of Environment & Science (Qld)
Steve Unwin	Wildlife Health Australia
Tamsyn Stephenson	Adelaide Koala and Wildlife Centre
Tania Bishop	Wildlife veterinarian, Qld
Tiggy Grillo	Wildlife Health Australia
Tim Portas	RSPCA Queensland
Tracey Wilson	Mosswood Wildlife
Valentina Mella	University of Sydney
Vickii Lett	NSW Wildlife Information, Rescue & Education Service (WIRES)

The authors would like to thank Wildlife Health Australia for facilitating provision of data from the national Wildlife Health Information System (eWHIS). Wildlife health data were provided by Adelaide Koala and Wildlife Hospital, Agriculture Victoria, Australia Zoo, Currumbin Sanctuary, Dept of Agriculture and Fisheries, Qld, Dept of Primary Industries and Regional Development, WA, Dept of Primary Industries and Regions, SA, Dept of Primary Industries, NSW, Dr Mike Cannon, Healesville Sanctuary, James Cook University,

Melbourne Zoo, Natural Resources and Environment, Tas, RSPCA Qld, Taronga Zoo, University of Adelaide, University of Queensland, University of Sydney, Western Plains Zoo, Wildlife Health Victoria: Surveillance and ZoosSA.

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https://doi.org/10.25910/gfg9-vk76

https://ses.library.usyd.edu.au

The National Koala Disease Risk Analysis Report – Appendices version 1.2 (University of Sydney) is available as a separate document, https://doi.org/10.25910/xkkv-nk38

Suggested Citation:
Vitali SD, Reiss AE, Jakob-Hoff RM, Stephenson TL, Holz PH and Higgins DP (2023) National Koala Disease Risk Analysis Report version 1.2. University of Sydney.

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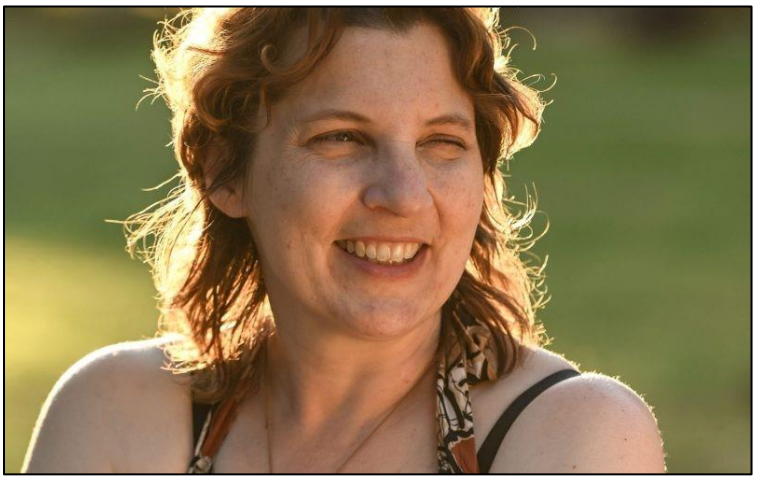
Dedication



This report is dedicated Dr. Joanna Griffith, a courageous and spirited woman with a passion for all wildlife, but particularly for the koalas that were the focus of her distinguished veterinary career. Right up until the week before her death, Jo was involving herself in the KDRA process, sharing her knowledge and resources, and providing valued feedback. She was a dear friend as well as a respected colleague to many people working with koalas, and her tenacity and spirit have been an inspiration to us all.

Contents

Definitions

Term	Definition
Acceptable level of risk	The maximum overall exposure to *risk* that should be accepted, based on the benefits and costs involved.
Acute disease	A disease occurring in a short timeframe, regardless of severity of clinical signs.
Antibody	A protein made by the body's immune cells in response to an *antigen*, which acts to combine with and remove the *antigen* from the *host's* body.
Antigen	Any substance that causes the body to mount an adaptive immune response, especially the production of *antibodies*, against that substance. Antigens from infectious agents are commonly targets in diagnostic tests to detect presence of those agents.
Antigenaemia	The presence of *antigen* in the blood of the host.
Arthropod	Invertebrate animals (such as insects, spiders and mites) that have a segmented body, jointed appendages and an exoskeleton.
Association	A statistical relationship between two variables. Two variables may be associated without a causal relationship.
Biosecurity	The set of precautions taken to minimise the risk of introducing a *parasite* or *infectious disease* into an animal (or human) population, or to a group or individual.
Captive/captivity	An animal that lives under human control or care, either temporarily or permanently.
Carrier	A *host* that harbours a *pathogen* in its body without manifesting *clinical signs*, thus acting as a potential source or distributor of *infection.*
Causation	A situation where the exposure to a *hazard* is responsible for the effect.
Chronic disease	A disease occurring over a long timeframe, regardless of the severity of clinical signs.
Clinical sign	Observed, objective changes in the normal healthy state, bodily function or behaviour of an animal.
Colonisation	The presence of *pathogens* on a body surface (e.g. skin, mouth, intestines or airway) without causing *disease* in the individual.
Contagious hazard	*Infectious diseases* that are spread through (direct or indirect) contact with infected individuals e.g. *Chlamydia*. Not all infectious diseases are contagious.
Critical control point	A key point in a *hazard's* biological pathway at which practical *risk management* strategies could be implemented.
Cytokine	Substances such as interferon, interleukin and growth factors, that are secreted by certain cells of the immune system and have an effect on other cells.
Dedicated equipment	Equipment that is dedicated for sole use for an animal, task or area, with the purpose of reducing the risk of cross-contamination.
Diagnostic test	Any procedure used to aid in the characterisation of the cause or nature of a *disease.*
Disease	Any disturbance in the health or function of an animal or human (includes diseases due to both infectious and non-infectious causes).
Disseminated intravascular coagulation	A serious *disease* in which the proteins that control blood clotting become overactive.
DNA (deoxy-ribonucleic acid)	The molecule that carries genetic information for the development and functioning of an organism.

Term	Definition
Dyspnoea	Shortness of breath or difficulty breathing.
Endemic	A *disease* or *parasite* regularly found among particular populations or in a specified geographic area.
Endogenous KoRV transmission	The transmission of KoRV within the koala genome by inheritance, which occurs only with the endogenous form of KoRV.
Endogenous retrovirus	Retrovirus which is incorporated into *germ cells* of the host and therefore is inherited by successive generations.
Exogenous KoRV transmission	The transmission of KoRV from koala to koala by means other than inheritance. This is thought to occur with exogenous forms of KoRV.
Exogenous retrovirus	Retrovirus that is incorporated only into the *somatic cells* of the host and therefore is not inherited.
Exotic (disease)	A *pathogen* not known to be present in a specified geographic area.
Fomite	Any inanimate object that can harbour *parasites* and thereby play a role in *transmission* of those parasites.
Genotype	The *DNA* sequence at a specific position within the genome of the *pathogen,* also known as sequence type, subtype, variant or strain.
Germ cell	A gamete cell (egg or sperm).
Habitat degradation	A reduction in the quality of the habitat available, such that it affects the carrying capacity, health or welfare of koalas in the habitat.
Habitat fragmentation	Loss of connectivity between areas of habitat supporting koalas, independent of the absolute amount of habitat available.
Habitat loss	Any process which results in a reduction of the absolute amount of habitat available to koalas.
Haematogenous dissemination	Spread via the blood system of a *host.*
Hazard (disease)	Biological, physical or chemical factors in the animal's environment that can have negative impacts on their health. See also *disease.*
Host	Any animal harbouring a *parasite*, regardless of whether it plays a role in the further *transmission* of the parasite.
Hyperoxaluria	Elevated oxalate levels in the urine.
Immune modulation	Changes to the function of the *immune system*; may be stimulatory, suppressive or a shift in focus.
Immune system	The collection of organs, cells and molecules that together provide the animal with defence against invading organisms.
Inapparent infection	An infection that is associated with clinical signs that are only identifiable with specialised diagnostic equipment or via internal or microscopic examination. In particular, chlamydial infections where there are no outward signs of disease, but internal urogenital pathology is present and detectable via ultrasound examination or histopathology.
Incubation period	The time that elapses between *infection* with a *parasite* and the onset of *disease.*
Infection	The entry and development or multiplication of a *parasite* in the body of a *host*, where it may or may not cause *disease.*
Infectious disease	The debilitating effects of *infection* or *infestation* by a *parasite*. It is possible for a *host* to be infected by a parasite but to show no *clinical signs* of *disease.*
Infectious hazard	A *hazard* which involves the entry and development or multiplication of a *microparasite* or *macroparasite* in the koala, where it may or may not cause *disease.*

Term	Definition
Infestation	When a *macroparasite is* present on the external surface of a *host,* regardless of whether the infestation results in *disease.*
Integration site	In terms of KoRV, the position within the koala genome where KoRV undergoes *integration* into the koala *DNA*.
Integration	The process of incorporation of *KoRV* into the *host* koala *DNA,* also known as *insertion.*
KoRV traits	The range of characteristics by which KoRV presence in a *host* may be quantified or described. Includes viral load, *proviral load*, presence or load of variants and presence or load of certain genetic markers (e.g. *pol* gene).
Latent infection	A persistent *subclinical infection* in which the *parasite* is dormant but has the potential to become active and cause *disease* or be *transmitted* in the future.
Latent phase (virus)	The stage of the virus lifecycle when it generally lies dormant within *host* cells.
Listed koala	Combined populations of koalas in Qld, NSW and the ACT.
Lytic phase (virus)	The active phase during which the virus replicates within the *host* cell and releases a new generation of viruses when the infected host cell lyses.
Macroparasite	*Multicellular parasites* such as worms, fleas and *arthropods* that are typically visible to the naked eye.
Mesopredator	A mid-ranking predator in the middle of a trophic level, that typically preys on smaller animals. In koala habitat, feral cats and foxes are considered to be mesopredators.
Microbiome	The assemblage of living microorganisms present in a particular environment (including the body or a part of the body).
Microparasite	*Parasites* such as bacteria, viruses and fungi that are typically invisible to the naked eye.
Mitigation	To apply a treatment or action that lessens or decreases the severity or likelihood of a *risk.*
Necrosis	The death of most or all of the cells in an organ or tissue due to disease, injury, or failure of the blood supply.
Non-infectious hazard	A *hazard* that is not living and cannot be *transmitted* to a *host* from another *host* or from the environment.
Non-pathogenic	An organism or strain not causing disease.
Northern koala	Koalas found in Qld, NSW and the ACT.
Opisthotonus	A state of severe hyperextension in which an individual's head, neck and spinal column enter into an "arching" position.
Overt	In the context of the KDRA, *disease* that is plainly apparent without the use of specialised diagnostic equipment.
Parasite	A biological agent that lives on or within a *host* and survives at the expense of the host regardless of whether a *disease* state follows. This includes both *microparasites* (e.g. bacteria, viruses) and *macroparasites* (e.g. helminths, arthropods).
Pathogen	Any organism causing *disease.*
Pathognomonic	*Clinical signs, diagnostic test* results or other findings which are unique to a particular diagnosis.
Personal protective equipment	Anything worn by a person to keep them healthy and safe when undertaking a task.
Pol KoRV	KoRV which possesses the *pol* gene and is therefore capable of integrating into the koala host DNA and replicating; "replication-competent" KoRV.

Term	Definition
Pol-negative koala	A koala that is infected with KoRV that does not possess the *pol* gene and is therefore incapable of replication.
Pol-positive koala	A koala that is infected with KoRV possessing the *pol* gene ("replication-competent" KoRV).
Polyparasitism	The presence of multiple *parasites* on, or in, the same *host.*
Precautionary principle	The principle by which, if there is limited information, a *risk* is assumed to exist (and require management), until proven otherwise.
Prevalence	The proportion of the *host* population with *infection*, *disease* or *antibody* presence, often expressed as a percentage.
Proviral load	The amount of *provirus* within a host.
Provirus	A virus genome that is integrated into the DNA of a host cell. In terms of KoRV, refers to the transcribed *DNA* copy of *KoRV* which is incorporated into the koala genome.
Pruritus	Severe itching of the skin.
Quarantine	Isolation and observation of an animal in a biosecure setting for a specified period of time to allow *diseases* of concern to be detected and treated, and to prevent all new exposures to *parasites* of concern.
RecKoRV	Defective KoRV elements that appear to be endogenous but lack the *pol* gene and are therefore not capable of *replication.*
Rehabilitation facility	A facility (large or small) for the treatment and care of injured, orphaned, or sick wild animals so that they can be released back to the wild.
Replication-competent (retrovirus)	In terms of KoRV: KoRV that contains the full gene complement and is therefore capable of integrating into *host DNA* and replicating to produce additional virus.
Reservoir	A species which can harbour a *pathogen* indefinitely with no ill effects. Reservoir *hosts* provide an environmental 'reservoir' for a *pathogen* and generally don't get sick from *infection*.
Riparian habitat	Habitat occurring along water courses and water bodies.
Risk	The likelihood of encountering some form of harm, loss or damage, combined with the severity or consequence of the event.
Risk analysis	The process composed of problem description, hazard identification, risk assessment, risk management and risk communication.
Risk assessment	The evaluation of the likelihood and the consequences of entry, establishment or spread of a pathogenic agent within a specified animal population or environment.
Risk management	The process of identifying, selecting and implementing measures that can be applied to reduce the level of *risk*.
RNA (ribonucleic acid)	A nucleic acid present in all living cells that has structural similarities to DNA.
Screening test	Any procedure used to aid in the identification of individuals in a population that have subclinical infections, so that appropriate action can be taken.
Sensitivity (test)	The likelihood that a truly positive (infected) individual will return a positive test result.
Sequence type	See *genotype.*
Somatic cell	Any cell of a living organism other than the *germ cells.*
Southern koala	Koalas originating from SA and Vic free-ranging populations.
Specificity (test)	The likelihood that a truly negative (non-infected) individual will return a negative test result.

Term	Definition
Strain (of organism)	See *genotype*.
Subclinical infection	A state in which an *infectious hazard* is present in the *host* without any clinical signs of illness.
Surveillance	A systematic ongoing program of investigation designed to establish the presence, extent of or absence of a *disease*, or of *infection*, or presence of a *pathogen.* It includes the examination and testing of animals for c*linical signs, antibodies* or the presence of a *pathogen* and the timely dissemination of information so that action can be taken.
Trans-faunation	Oral administration of intestinal content to restore bacteria to the gut.
Transmission	The process by which a *parasite* passes from a source of infection to a new *host.*
Transparency (of process)	Comprehensive documentation of all data, information, assumptions, methods, results, discussion and conclusions used in the *risk analysis.* Conclusions are supported by an objective and logical discussion and the document is fully referenced.
Triage	The process of organising patients according to the severity of their condition and treating each patient within an appropriate time frame. Triage also includes an assessment of the viability of the patient, and whether euthanasia should be considered due to the severity of *disease* and associated welfare concerns.
Trypanosomiasis	Infection of a host by trypanosome *parasites.*
Vector	A living organism (frequently an arthropod) that transmits an infectious hazard from one host to another.
Virion	The complete, infective form of a virus outside a host cell.
Wet bottom	Chronic staining and wetness of the rump of koalas, associated with urinary incontinence and often caused by urinary tract infections, particularly *Chlamydia.*
Wildlife hospital	A hospital or clinic that provides veterinary assessment, treatment and care for free-ranging wildlife.
Zoonosis	A *disease* of animals that can be transmitted to humans.

Abbreviations and Acronyms

ABBREVIATION	
ACT	Australian Capital Territory
CCP	Critical control point
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DNA	Deoxyribonucleic acid
EAG	Expert Advisory Group
eWHIS	(National) electronic wildlife health information system
FeLV	Feline leukaemia virus
h	Hours
ha	Hectares
IFNγ	Gamma interferon
IUCN	International Union for the Conservation of Nature
KHH	Koala Health Hub
KoRV	Koala retrovirus
LCAT	Latex cryptococcal antigen test
LFA	Lateral flow immunochromatography assay
MLST	Multi-locus sequence typing
MVA	Motor vehicle accident
NSW	New South Wales
NT	Northern Territory
NZ	New Zealand
OIE	Office International des Epizooties (now World Organisation for Animal Health)
ON	Oxalate nephrosis
PCR	Polymerase chain reaction
PhaHV	Phascolarctid herpesvirus
Qld	Queensland
qPCR	Quantitative polymerase chain reaction
RMO	Risk mitigation option
RNA	Ribonucleic acid
SA	South Australia
SME	Subject matter expert
T_a	Ambient temperature
Tas	Tasmania
T_b	Body temperature
TNZ	Thermoneutral zone
Vic	Victoria
WA	Western Australia
WHA	Wildlife Health Australia
WOAH	World Organisation for Animal Health (formerly OIE)
ZAA	Zoo and Aquarium Association

Executive Summary

- This document details a national disease risk analysis for the koala and identifies the knowledge base, information gaps, risk assessments and critical control points for koala disease hazards. Commitment of government funding for ongoing implementation of the Koala Disease Risk Analysis (KDRA) is recommended, including a process for ongoing stakeholder communication, review and future updating of the KDRA.
- The findings and recommendations of the KDRA should be embedded and operationalised in the context of the broader national Koala Recovery Plan. Resourcing to support national koala disease risk mitigation actions is highly recommended.
- The KDRA should be used as a key guiding document for decisions on koala disease risk prioritisation. It underpins and facilitates, but does not replace local context risk assessment.
- The national KDRA explores disease threats to all koalas in Australia: in captivity, in rehabilitation and in the wild. **Ten diseases** were identified as significant risks to koala populations requiring risk mitigation action (see *Section 1.1 Significant Disease Hazards Identified*). In most instances, effective actions can be taken to reduce disease risks in wild koalas and many of the identified risk management options have the capacity to mitigate multiple disease risks to koalas.
- A comprehensive threat analysis found **decline in environmental health** to be the principal driver of disease impacts in koalas. Consequently, preservation and restoration of habitat is a critical component of mitigating disease risks to free-ranging koalas.
- Clear linkage between disease hazards and other non-disease drivers indicates that **integrated strategies** are required, that simultaneously manage and prioritise multiple threats, including disease. The national KDRA will enable the integration of health and disease risk mitigation actions into broader koala conservation efforts nationally.
- The **many knowledge gaps** identified through the KDRA should be used to guide research prioritization for koala health and disease. Disease hazards assessed as high risk through the KDRA, or where a low level of confidence in the risk assessment was identified, are high priorities for further research.
- The KDRA provides the basis for the development of a nationally-agreed approach to koala disease management and risk mitigation. This should include **nationally-agreed standards** for diagnosis, triage, investigation, treatment, care and record-keeping of diseased koalas to support best practices in koala health management.
- To build community confidence in koala conservation decisions, funding for koala conservation should address all threats facing koalas in an integrated manner, underpinned by scientifically robust information.

1 Summary of Findings and Recommendations

The national focus of the Koala Disease Risk Analysis (KDRA) provides a clear, evidence-based assessment of koala disease which will be of value in evaluating disease risk at all regional levels and in all management situations (captive, rehabilitation, free-ranging).

Participants in the KDRA identified their ideal future for koala health in this Vision Statement:

> ***"Sustainable, resilient and healthy populations of koalas, living in positive welfare within healthy ecosystems across their range. Koalas are well-managed in their local context and populations are supported by robust and consistent legislation, informed community engagement and long-term funding."***

Identification and analysis of risks and the recommendations arising from the KDRA were underpinned by this vision.

This disease risk analysis followed the current gold-standard methodology endorsed by the International Union for the Conservation of Nature (IUCN) and the World Organisation for Animal Health (WOAH). It was conducted over 12 months and incorporated a series of facilitated online meetings and workshops involving 44 disease and wildlife management experts, government representatives, non-government organisations and other stakeholders. A feature of the KDRA was the uniformly shared concern for the conservation and welfare of koalas and willingness to collaborate among this wide range of stakeholders.

1.1 Significant Disease Hazards Identified

The KDRA explored both infectious and non-infectious disease threats to all koalas in Australia, whether in captivity, in rehabilitation or in the wild[1]. Through a systematic refinement process, 13 disease hazards were identified requiring detailed risk assessment (see Table 1). Of these, 10 hazards (listed below in order of importance) were assessed as requiring active management because they present significant risks to koala population viability and resilience and to individual koala health and welfare:

1. *Chlamydia* spp.
2. koala retrovirus
3. heat stress
4. predator attack trauma
5. thermal burn trauma
6. *Cryptococcus* spp.
7. motor vehicle trauma
8. neoplasia
9. oxalate nephrosis
10. sarcoptic mange

[1] In the context of the KDRA, disease is defined as "any disturbance in the health or function of an animal or human" and includes diseases due to both infectious and non-infectious causes.

Table 1 Overall estimates of risk for koalas for diseases selected for detailed risk assessment. For further details, and for overall risks to humans and other species, see individual disease hazard risk assessments in Section 5.

Mod = moderate risk; Neg = negligible risk; [1] KoRV overall risk determined separately for northern koalas and southern koalas;
[2] oxalate nephrosis overall risk to individual koalas determined separately for Mt Lofty Ranges (MLR) population and other populations.
Note: Disease hazards assessed as high risk through the KDRA, or where a low level of confidence in the risk assessment was identified, are high priorities for further research.

	Chlamydia	Koala Retrovirus (KoRV)	Heat stress	Predator attack trauma	Thermal burn trauma	*Crypto-coccus*	Motor vehicle trauma	Neoplasia	Sarcoptic mange	Oxalate nephrosis	*Actino-myces*	Herpes-viruses	Trypano-somes
Overall risk estimates for koalas (for risks to humans and other species, see Section 5 KDRA Report)													
Koala population resilience & viability	High	High (north) Mod (south)[1]	Mod	Mod	Mod	Mod	Low	Low	Low	Low	Neg	Neg	Neg
Koala individual health & welfare	High	High (north) Mod (south)[1]	High	High	High	Mod	Mod	Mod	Mod	High (MLR) Low (other)[2]	Mod	Mod	Mod
Level of confidence in assessment													
	High	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low	Low

1.2 Recognition of Spatial Variation in Disease Risks

Disease threats to koalas vary across their geographic distribution, and whether a koala is in captivity, in rehabilitation or in the wild. Given the scope and national focus of the KDRA, risk assessments generally took a 'whole of species' approach, except where current evidence clearly indicated a significant variation in disease occurrence (e.g. koala retrovirus in northern vs southern koalas).

1.3 Knowledge Gaps and Refinement

In common with the state of knowledge of wildlife disease in general, the KDRA identified substantial gaps in current scientific knowledge of the epidemiology and regional prevalence of many disease hazards (see *Section 8 Key Knowledge Gap Summary* for an overview). For this reason, this qualitative analysis was based on the best available information, combining a comprehensive literature review and expert opinion. The intention is that this risk analysis will be continuously refined through future reviews, as further research helps to close the identified knowledge gaps.

1.4 Drivers of Disease

While disease is a natural part of ecosystems, disease impacts are inextricably linked to a number of other threats faced by koalas, and they place significant additional pressure on wild koala populations already suffering the cumulative impacts of severe non-disease threats. To identify and understand the underlying drivers of disease in this wider context, KDRA participants conducted a comprehensive threat analysis. This provided a framework for the identification of causal effect pathways and the points on these pathways where the most effective risk management intervention could take place (critical control points). To successfully manage disease risk to koalas, it is necessary to understand the linkage of disease to these non-disease drivers and to develop integrated strategies that simultaneously manage multiple threats in ways which are appropriate to the local situation and scale. For instance, decline of environmental health – particularly habitat loss, degradation and fragmentation – is recognized as a principal driver of disease in koalas. This is further exacerbated by the effects of climate change, including increased number and severity of bush fires, floods and droughts.

1.5 Disease Risk Management

Effectively mitigating disease risks in koalas is a complex task, requiring active participation from all levels of government and community over a long term with significant funding and resourcing[2]. The KDRA identified a range of risk mitigation options for the 13 disease hazards undergoing detailed risk assessment. Risk mitigation options for the ten disease

[2] See *National Guidelines for the Management of Disease in Free-ranging Australian Wildlife* https://wildlifehealthaustralia.com.au/Portals/0/Documents/ProgramProjects/National_Guidelines_Management_Disease_Freeranging_Aust_Wildlife_Nov_2020.pdf

hazards assessed as requiring active management were evaluated for effectiveness and feasibility and have been prioritised by importance.

Many of the identified risk management options have the capacity to mitigate multiple disease risks to koalas. In particular, the preservation and restoration of habitat and habitat connectivity was identified as a critical component of disease risk mitigation for free-ranging koalas. In addition, preventing introduction of pathogens is more cost effective than eradication; thorough action-specific risk assessment should be conducted for any action involving movement of animals.

1.6 Guiding Principles and General Recommendations

The following guiding principles and general recommendations for disease risk mitigation were developed through extensive consultation with stakeholders in koala health.

1.6.1 Guiding principles

Several of the recommendations of the National Koala Disease Risk Analysis (KDRA) were developed into a set of eight "guiding principles for effective action", designed to underpin all actions addressing disease risks facing koalas[3].

- The **KDRA and its recommendations** should be used to **inform and prioritise disease risk mitigation actions** for health and welfare threats facing koalas, with the greatest disease risks receiving the most focus.
- The importance of **good quality koala habitat** as a principal factor in disease risk mitigation should be recognised and prioritised.
- **Climate change** has been identified as a driver of many important disease hazards of koalas (both infectious and non-infectious). This should be acknowledged and incorporated into plans for action.
- Co-infections, stress and other **causes of debilitation should be minimised** wherever possible to reduce cumulative risk of disease.
- The **KDRA should be used by the National Koala Recovery Team** as a primary resource to inform on koala health and welfare risk and response.
- **Nationally-agreed, standardised and coordinated protocols, guidelines and data sets** for koala health and disease are necessary for the effective and streamlined management of koala disease risk.
- Funding allocations to address koala health and welfare issues should be accompanied by **scientifically robust justifications** to build community understanding of, and confidence in, koala conservation decision making.

[3] The accepted definition of "disease" incorporates all threats to koala health and welfare, both infectious and non-infectious. Of the top five hazards to koalas identified in the KDRA, two (*Chlamydia* and KoRV) are infectious and three (heat stress, predator attack and burns) are non-infectious.

- **The collegiate spirit** of the KDRA process should be fostered to **continue collaborative relationships** between managers of koala populations and koala clinical and research working groups.

1.6.2 General recommendations

The following general recommendations were developed, based on the KDRA as a whole, including the processes of non-disease threat analysis, literature review , stakeholder consultation, hazard refinement and individual disease risk assessments.

Detailed, prioritised recommendations for each of the 13 disease hazards are included in the respective risk assessments. The General Recommendations below also apply broadly across all disease hazards of concern, as noted in the *Recommendations* section for each disease hazard.

High priority general recommendations

- G1 Recognise and prioritise habitat preservation, restoration and revegetation as principal mitigators of disease risk.
- G2 Maintain or increase koala population size and genetic diversity to encourage retention of the most robust koala genetic profiles. New information on the influence of koala genetics on specific disease risks should be incorporated promptly into decision-making.
- G3 Improve national population estimates and ensure ongoing population health monitoring for koalas.
- G4 Undertake a national population and habitat viability analysis for koalas[4].
- G5 Develop robust, longitudinal and nationally-agreed data sets on causes of illness & death in free-living koalas.
- G6 Develop a nationally-agreed, standardised and shareable system for capturing health and disease data (captive, wild and rehabilitation).
- G7 Develop nationally-agreed approaches to diagnosis, triage, investigation, treatment, care and record-keeping of diseased koalas.
- G8 Develop nationally-agreed, post-release identification and monitoring protocols.
- G9 Support nationally-consistent best practice training for veterinary professionals and rehabilitators in care and treatment of diseased koalas.

Medium priority general recommendations

- G10 Develop nationally-agreed guidelines on biological sampling, sample storage and diagnostic laboratory contacts.
- G11 Develop a national framework (including training) for emergency preparedness and response for wildlife.

[4] See www.cbsg.org/our-approach/workshop-processes/phva-workshop-process

- G12 Support the involvement of veterinary professionals in koala rehabilitation through appropriate funding, regulatory controls, policies and procedures.
- G13 Deliver rapid, high-quality investigation and response to unexpected outbreaks of disease in koalas.
- G14 Develop communication tools to improve clarity in messaging, raise awareness and encourage behaviour change around drivers of health and welfare threats to koalas.
- G15 Determine the priority order of knowledge gaps identified in the KDRA and develop them into a Research Plan.
- G16 Develop and implement a nationally-consistent approach to translocation risk assessment.

Lower priority general recommendations

- G17 Develop personal mental health and welfare care plans for all those involved in rescue, treatment and care of injured wildlife.
- G18 Increase awareness and implementation of good biosecurity practices during field work, treatment and rehabilitation.
- G19 Update the KDRA through a regular review process every two years.
- G20 Develop a communication strategy for the KDRA.
- G21 Review reporting processes into the national wildlife health information system (eWHIS).

The reader is also referred to *Section 8 Key Knowledge Gap Summary* and to the detailed recommendations for each of the 13 disease hazards in *Section 5 Risk Assessments*.

1.7 Distribution and Dissemination of the KDRA

1.7.1 Report circulation and familiarisation

- Distribution of the updated KDRA should be coordinated through the Koala Health Hub (KHH, University of Sydney), Wildlife Health Australia (WHA) and IUCN, with support from the Commonwealth government, so that the report is available to stakeholders as soon as possible.
- This version of the report will be made publicly available on national and international platforms, including the University of Sydney eScholarship repository (https://ses.library.usyd.edu.au), the IUCN-SSC Conservation Planning Specialist Group website, the WHA website and the KHH website, and will act as an exemplar of a best-practice national DRA for an Australian wildlife species.
- A detailed strategic communication plan, incorporating the information needs of the wide range of koala stakeholders, should be supported, including communication webinars and other presentations to familiarise stakeholders to the KDRA (see also *G20*). This will enable broad stakeholder familiarisation of the final report.

1.7.2 Ongoing implementation and alignment of the KDRA

- Funding should be sought to enable ongoing implementation of the recommendations from the KDRA.
- Ongoing implementation of the KDRA should identify detailed strategies, actions, time frames, assignment of roles and responsibilities, cost estimates and sources of funding together with a monitoring and evaluation framework.
- Agreement should be reached between major national stakeholders in koala health and management (e.g. the Koala Recovery Team, government agencies, KHH, WHA and the National Koala Monitoring Program [NKMP]) to determine capacity and remit to progress the recommendations from the KDRA.

2 Introduction

2.1 Background and Justification for the Koala Disease Risk Analysis

In the context of the Koala Disease Risk Analysis (KDRA), disease is defined as "any disturbance in the health or function of an animal or human" [1]. Disease has long been recognised as a threat to the viability of koala (*Phascolarctos cinereus*) populations in the wild, and to the welfare of individual koalas. For over 30 years, the impacts of chlamydiosis have been a major challenge for management of the species [1-4], and in the last 20 years, koala retrovirus (KoRV) has been identified as a threat with complexities that are only just beginning to be understood [5-8]. Non-infectious hazards such as motor vehicle and predator trauma are ongoing, and in 2019-20, the suffering of koalas in the Australian bushfires had veterinarians and rehabilitators grappling with the management of burns on an unprecedented scale [2, 3]. The last few years have seen the identification of a number of novel koala pathogens such as *Actinomyces* [4] and *Chromobacterium* [5]. Diseases which are well-recognised in other species, such as sarcoptic mange, now appear to be also establishing in koala populations [6, 7]. This national KDRA provides a means of bringing together the most recent knowledge on disease hazards, determining the most important disease threats for koalas as a species, identifying risk management options and documenting current gaps in knowledge.

The drivers of disease in koalas are complex and often incompletely understood. There is currently no nationally-agreed approach to disease monitoring, investigation, treatment and record keeping for koalas, although work is under way to better incorporate health monitoring into the National Koala Monitoring Program (NKMP - see *2.5 Aligned Research Programs*). A national KDRA provides a comprehensive evidence base to inform disease monitoring strategies for the NKMP. Identification of knowledge gaps can inform and focus koala research priorities at the national level.

Although disease is a natural phenomenon, population-level impacts of disease on wildlife occur where the natural balance between the health of the environment and animals within it is disturbed. As such, disease impacts are inextricably linked to a number of other threats faced by koalas, such as habitat loss and climate change (see *Section 3.6 Non-disease Threats and Their Impact on Disease*) that drive or exacerbate the negative impacts of disease on koala populations [8, 9]. Identifying the relationship between disease and other threats through the national KDRA highlights the interconnectedness of all threats to koala conservation, and provides the necessary holistic context to support effective management of koala disease risks [9, 10].

There are significant regional differences in the disease manifestations of a number of key disease hazards of koalas, including chlamydiosis and koala retrovirus [11]. The non-disease threats facing koalas also differ in their regional impact across the koala's distribution [10].

A KDRA which evaluates disease risk at the national level and facilitates input from a broad range of stakeholders with first-hand knowledge and understanding of regional differences in disease manifestations, enables the information sharing needed to inform regional decisions on disease risk mitigation.

To this end, the *National Recovery Plan for the Koala* identifies the importance of building and sharing knowledge, and collaborating with a range of stakeholders to protect koalas [12]. In particular, it identifies the need for a consistent approach and guidance on matters relating to koala health and disease, which incorporates the knowledge of veterinary experts, koala welfare and rehabilitation experts, disease research professionals, Traditional Owners and other stakeholders in koala health. The Commonwealth initiative to develop a national KDRA via the *Bushfire Recovery for Wildlife and their Habitats* program recognises the importance of developing a nationally-relevant document on koala disease risk, to assess current knowledge, identify gaps, and propose disease management strategies.

2.2 Koala Disease Risk Analysis Purpose

The purpose of the KDRA is to:

- Consolidate available knowledge about koala diseases and disease risks.
- Record gaps in knowledge.
- Identify potential research priorities.
- Inform nationally-agreed guidelines for koala disease risk mitigation, disease risk assessment for koala movements, disease screening protocols, koala health examination, sample collection, interpretation of diagnostic test results and biosecurity practices for koala management.
- Communicate risks of disease in koalas, and outputs of the KDRA, to stakeholders.

2.3 Koala Disease Risk Analysis Questions

The KDRA addresses the following questions:

- Where is disease risk placed in the context of other threats facing koalas?
- What are the known and possible disease threats to the koala?
- Which of these diseases are the priorities for action?
- What disease risk mitigation actions will best improve the future viability of koala populations regionally and nationally?
- What are the gaps in current disease knowledge and how can these be addressed to increase confidence in risk assessments?

2.4 Koala Disease Risk Analysis Scope, Focus and Vision

The KDRA was confined to the following scope and focus:

- The koala, *Phascolarctos cinereus*, a single species with no close relatives.

- All koala populations in Australia, both free-living and captive.
- Non-disease threats with potential to directly or indirectly impact disease risk.
- Disease hazards only identified in koalas located overseas were excluded.

For the purpose of the KDRA, a "disease" was defined as "any disturbance in the health or function of an animal or human" [1]. The KDRA considered all infectious and non-infectious disease hazards to which koalas may be susceptible, including diseases only known to be associated with the captive state, and disease syndromes which did not have a clear identified cause.

Stakeholders developed a *Vision Statement* to express the shared aspirations for the health and conservation management of koalas:

> ***Sustainable, resilient and healthy populations of koalas, living in positive welfare within healthy ecosystems across their range. Koalas are well-managed in their local context and populations are supported by robust and consistent legislation, informed community engagement and long-term funding.***

2.5 Aligned Research Programs

The KDRA was funded by the Australian Government as part of a suite of projects aimed at improving conservation outcomes for koalas. The purposes and outputs of the KDRA are achieved in alignment and collaboration with these other koala conservation initiatives, which are summarised in Figure 1.

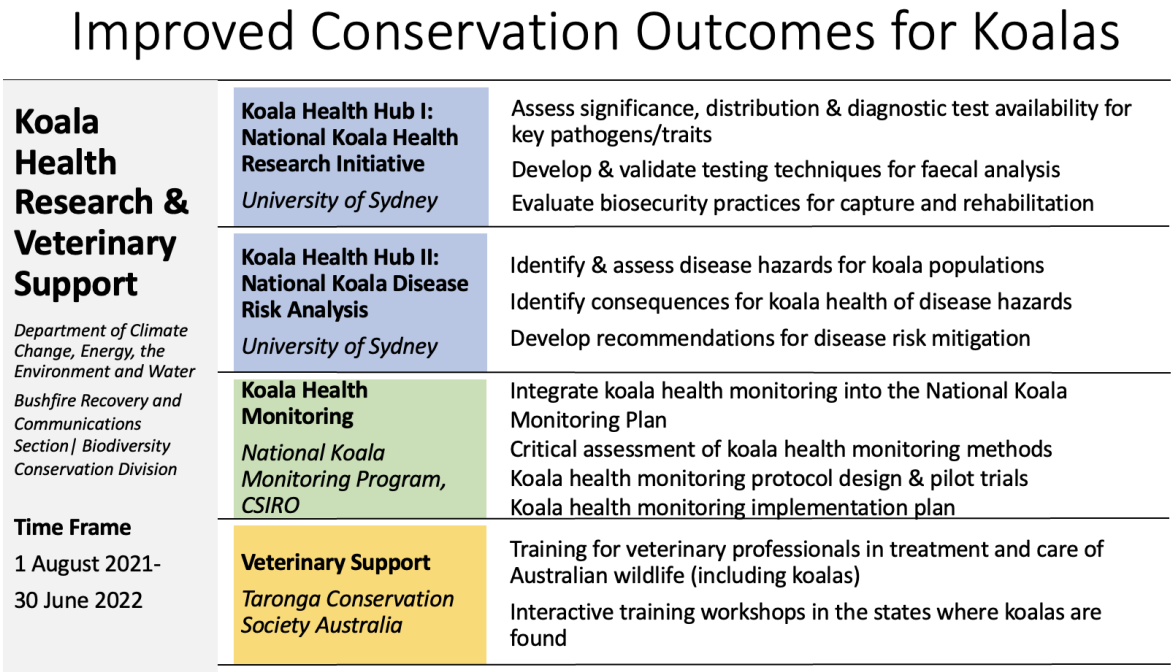


Figure 1 Koala conservation initiatives supported by the Department of Climate Change, Energy, the Environment and Water, August 2021 - June 2022

The Koala Health Hub (KHH) (https://koalahealthhub.org.au) is an initiative of the University of Sydney that benefits koala welfare and conservation by providing research services and expertise, and connecting researchers across the country with those responsible for koala care and management. The KDRA was conducted through the Koala Health Hub. In addition to the KDRA, the KHH led a number of nationally collaborative, priority, research investigations supported by the *Bushfire Recovery for Wildlife and their Habitats* program. The findings and progress of these investigations were incorporated into the KDRA.

The *National Koala Monitoring Program* (www.csiro.au/en/research/indigenous-science/Managing-Country/Koala-monitoring-program) is an initiative led by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in consultation with government (state, territory and local), natural resource management organisations, Indigenous Australians, community and industry groups, and researchers. Koala population monitoring is critical to understanding the impact of disease on populations. Local population disease surveillance programs are undertaken at various times, and in association with other koala monitoring activities. However, such programs are reliant on engagement by particular research groups and, where health screening is not part of project planning from the outset, the effectiveness of the surveillance effort can be limited. An initiative to incorporate health surveillance into the NKMP was undertaken as part of the *Bushfire Recovery for Wildlife and their Habitats* program and will also be informed by this KDRA.

The need for improved training of veterinary professionals in the treatment and care of wildlife, including koalas, was identified as a priority following the 2019-20 bushfires in eastern Australia. With the support of the *Bushfire Recovery for Wildlife and their Habitats* program, the Taronga Conservation Society Australia (TCSA) is providing training for veterinary professionals to address this need (https://taronga.org.au/education/veterinary-professional-training). The TCSA course, *Veterinary Professional Training in Wildlife Treatment and Care,* is aligned with the KDRA purpose of informing nationally-agreed guidelines for koala health and disease practices that may then be passed on to veterinarians in practice.

2.6 The Disease Risk Analysis Approach

2.6.1 DRA Framework

The disease risk analysis (DRA) framework and tools used in this KDRA are described in the *Manual of Procedures for Wildlife Disease Risk Analysis* endorsed by the IUCN-Species Survival Commission (IUCN-SSC) and the World Organisation for Animal Health (WOAH) [13]. This is a transparent, evidence-based process designed specifically for application to wildlife disease. It is underpinned by One Health: the recognition that the health of people, animals and their shared environment are interconnected [14]. As such, it promotes and facilitates the collaborative involvement in the analysis of multiple stakeholders who could be impacted by a wildlife disease issue or who can have a significant impact on the outcome

of the analysis. This includes decision makers as well as subject matter experts that can help ensure that decisions are based on the best available information. *Appendix 1* lists the stakeholders consulted through online meetings and workshops in the development of this KDRA.

The KDRA was undertaken by a small Project Team in consultation with a DRA Specialist Member of the IUCN-SSC's *Conservation Planning Specialist Group* to guide effective stakeholder engagement and neutral facilitation of the DRA process. The KDRA Project Team membership is listed in *Appendix 1*.

The overall DRA framework is comprised of six interlinked steps as shown in Figure 2.

Figure 2 The steps of the disease risk analysis process Jakob-Hoff et al. 2014 [13]

2.6.2 The "precautionary principle"

In many cases, current knowledge of the epidemiology and prevalence of koala diseases is incomplete or lacking (see *Section 8 Key Knowledge Gap Summary*), creating uncertainty regarding the likelihood or consequences of risk of a disease hazard. Where such limitations on available evidence were encountered, the "precautionary principle" was invoked [13], whereby a risk was assumed to exist (and require management), until proven otherwise.

2.6.3 Disease association vs causation

The concept of causation in disease is complex, and it is very rare for a single factor to cause disease in 100% of subjects. Studies of the statistical associations between a particular disease hazard and various disease manifestations are a common means of seeking understanding and identifying potential avenues for future research. However, such studies do not necessarily provide evidence for causation of the disease manifestation by the hazard in question. This is particularly the case for infectious disease hazards, where identification of statistical associations with disease commonly precedes evidence of a

mechanism whereby the infection causes disease. The KDRA process made every effort to identify disease associations in addition to causal links, and to make clear the distinction between the two.

Each detailed risk assessment within this report contains a section on *Associations with other disease hazards of koalas* where information on disease associations is summarised.

2.7 References

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3 Problem Description

3.1 The Koala Species

The koala is the only surviving member of the marsupial family *Phascolarctidae* [1, 2]. It is a tree-dwelling, leaf-eating marsupial which feeds on trees of the genera *Eucalyptus*, *Corymbia* and *Angophora* [3, 4]. It is recognised globally as one of Australia's most distinctive and iconic wildlife species and has major cultural and emotional significance to both Indigenous and non-Indigenous Australians [5-10]. Its iconic status makes it a significant tourism drawcard benefiting Australia's economy [11].

3.2 Koala Geographic Range and Habitats

The koala is widely, but patchily, distributed across eastern and southern mainland Australia (Figure 3), associated with the distribution of the tree species which are its predominant food source [12].

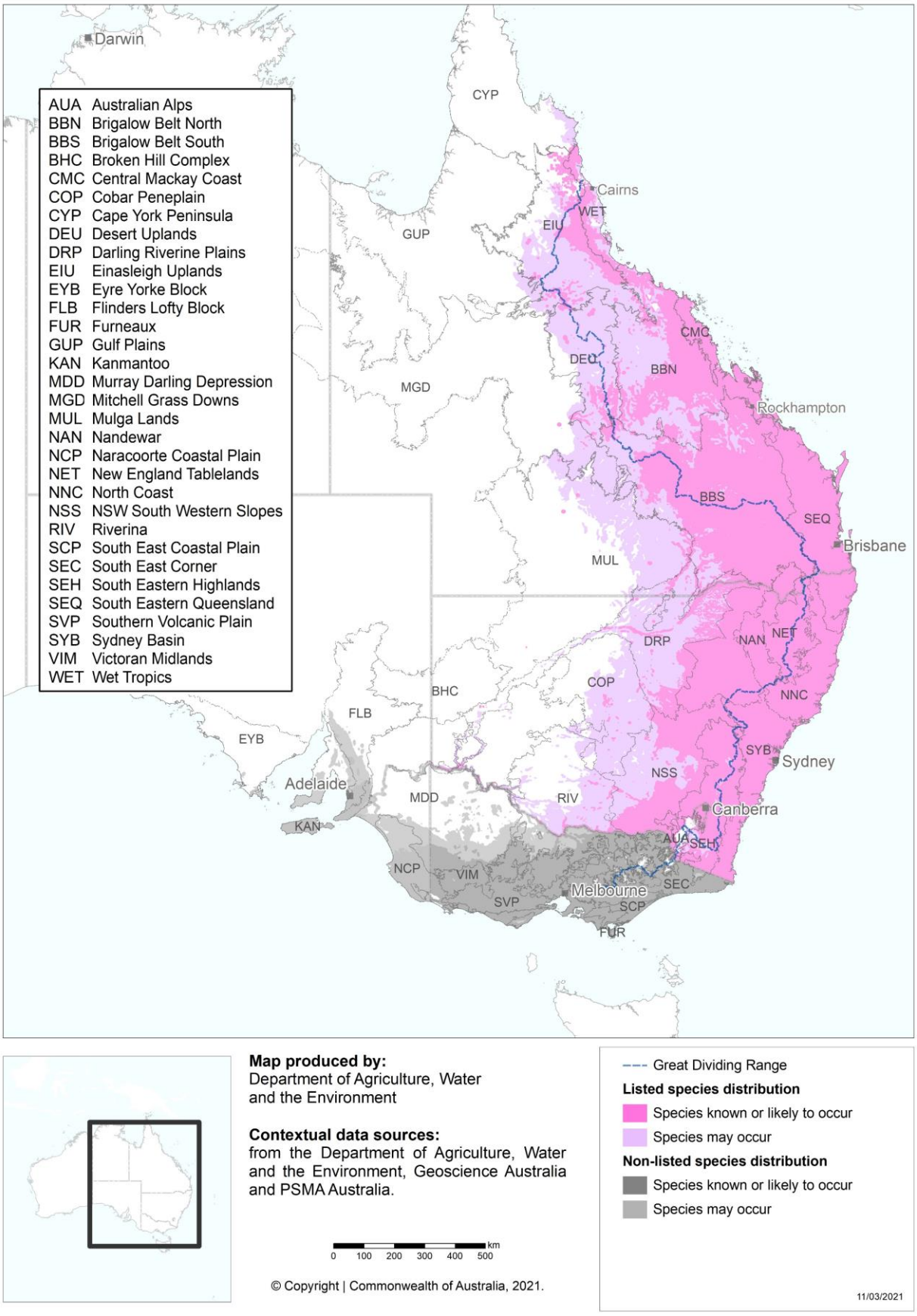

Figure 3 Modelled 2021 distribution (geographic range) of listed and unlisted koalas [13]

3.3 Conservation Status of the Koala

The koala presents a challenge for conservation because it is not uniformly classified as threatened throughout its range [14]. In Qld and NSW most populations are declining rapidly [12, 15], whereas populations in Vic and SA are relatively stable [13], or in some cases experiencing localised overcrowding in the available habitat [16]. The koala's conservation status reflects these regional differences in threats and conservation status, with the northern population of koalas (Qld, NSW and the ACT) determined to be a listed 'species' in 2012 under Section 517 of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). These koala populations are currently listed as Endangered [15]. The southern population (Vic and SA) is currently unlisted under the EPBC Act and under the legislation of those states. The conservation status of koalas is summarised in Table 2.

Table 2 International, national, state and territory conservation status of the koala [13]

Legislation	Conservation status
Environment Protection and Biodiversity Conservation Act 1999 *Phascolarctos cinereus* (combined populations in Queensland, New South Wales and the Australian Capital Territory)	Endangered
Nature Conservation Act 1992 (Qld) Koala (*Phascolarctos cinereus*)	Vulnerable
Biodiversity Conservation ACT 2016 (NSW) Koala (*Phascolarctos cinereus*)	Vulnerable
Nature Conservation Act 2014 (ACT) Koala (*Phascolarctos cinereus*)	Vulnerable
Flora and Fauna Guarantee Act 1988 (VIC) Koala (*Phascolarctos cinereus*)	Not listed
National Parks and Wildlife Act 1972 (SA) Koala (*Phascolarctos cinereus*)	Not listed
IUCN Red List of Threatened Species Koala (*Phascolarctos cinereus*)	Vulnerable

The KDRA adapted the terminology of the 2022 *National Recovery Plan for the Koala* [13] in referring to the various koala populations as follows:

- when referring to individuals or populations, the terms 'koala' or 'koalas' is used.
- the total population of the species in Australia is referred to as 'the koala' or 'the species'.
- the terms 'listed koala' or 'northern populations' are used when referring explicitly to the EPBC Act-listed koala (combined populations of Qld, NSW and the ACT). These may also be referred to individually by their state origin.
- the terms 'unlisted koala' or 'southern populations' are used for the collective populations of Vic and SA. These may also be referred to individually by their state of origin.

3.4 Jurisdictions for Koala Management

Across Australia, biodiversity conservation and protection are delivered through the combined efforts of the Australian Government, local, state, and territory governments, along with the actions of landholders, communities, Traditional Owners, the private sector, and non-government organisations [13].

The EPBC Act is the Australian Government's key piece of environmental legislation that provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places. These entities (including the listed koala) are defined in the EPBC Act as Matters of National Environmental Significance (MNES). Consequently, the listed koala is subject to regulatory decision making under the EPBC Act, which is triggered when an action has, will have, or is likely to have, a significant impact. These actions require referral to the Australian Government for assessment and approval under the EPBC Act to be carried out lawfully [13].

Management of koala health is influenced by a variety of cross-jurisdictional policies, legislation, regulations and programs, working through Commonwealth, state, territory and local government agencies. A range of non-government organisations, wildlife organisations, community groups, veterinary organisations and citizen scientists support koala health management (see below).

3.5 Stakeholders in Koala Health

A wide range of stakeholders (see *Appendix 1*) are involved in the investigation, recording and management of koala health [14].

Research is undertaken on the biology, epidemiology and clinical significance of various koala diseases. Disease research is undertaken principally by university academics, both within Australia and overseas, and often in partnership with rehabilitation facilities, koala hospitals and koala monitoring programs. Research priorities for koala health and disease are not currently coordinated at the national level.

A large number of **rehabilitation facilities and wildlife hospitals** across Australia care for sick, injured and displaced koalas. Most are privately run, but may receive funding from government sources. There is communication and collaboration within the koala rehabilitation community, and willingness by many to share their knowledge and experiences. However, there is limited capacity for strategic centralisation and coordination of experience. Consequently, most rehabilitation facilities develop their own protocols for biosecurity, disease management, diagnosis and treatment, based on local priorities and constraints, with variable levels of involvement of veterinarians or other disease experts. Most rehabilitators are volunteers who may not have scientific training; facilities collect data on koala admissions, but the level and quality of data varies significantly. In NSW and Qld, admission data are collated into online databases that are publicly available, and contain some information on the health status of cases [17, 18]. Veterinary involvement in

diagnosis, assessment and treatment varies between rehabilitation facilities, as does the capacity and funding to conduct diagnostic testing and disease screening. Rehabilitation facilities and veterinary hospitals receiving sick and injured free-ranging koalas largely maintain individual control of their data which is not centrally compiled or managed. However, this information has been used in collaboration with scientific researchers to inform disease prevalence, impacts on morbidity and mortality, and geographic disease distribution (e.g. [19-22]).

Zoos and other institutions that house koalas in captivity generally maintain individual medical records that are a potential source of detailed information on captive disease incidence and management. In the last 10 years, many of these institutions have converted to using the Species360 Zoo Information Management System (ZIMS) database for managing their medical records (www.species360.org). This system enables rapid and reliable information management and sharing between institutions to enhance understanding of disease in captive populations. Zoo veterinary personnel are often involved in an advisory or clinical capacity in support of rehabilitators, some through zoo-based wildlife hospitals, and often also have a role in emergency response within their jurisdiction.

Wildlife Health Australia (WHA; https://wildlifehealthaustralia.com.au/Home.aspx) is the national coordinating body for wildlife health in Australia. WHA administers the national electronic Wildlife Health Information System (eWHIS) database, a web-enabled, secure database capturing information relating to wildlife health surveillance and disease investigation in Australia. WHA receives wildlife health data from sources both within governments (including state and territory agricultural, environment and health agencies) and from sources outside of governments (such as university veterinary clinics and pathology departments, zoo wildlife hospitals and private veterinary practitioners). Other sources include the Australian Registry of Wildlife Health. WHA collates and moderates the data in eWHIS to ensure that it is as accurate as possible. WHA has a wide range of fact sheets on wildlife disease issues, with several focused on disease in koalas (https://wildlifehealthaustralia.com.au/ProgramsProjects/eWHIS-WildlifeHealthInformationSystem.aspx).

The **Australian Registry of Wildlife Health** (ARWH; https://arwh.org/about) is hosted by Taronga Zoo and is a diagnostic and resource centre for Australian wildlife health and disease. The Registry focuses on detecting and diagnosing endemic, emerging and exotic diseases of wildlife that could have impacts on Australia's trade/economy, biodiversity, tourism and human health.

The **Koala Health Hub** (KHH; https://koalahealthhub.org.au) is an initiative of the University of Sydney to benefit koala welfare and conservation by connecting people undertaking koala care and management with consensus and evidence-based information and quality-assured diagnostic testing. Their aim is to create an inclusive, diverse and innovative source

of support for koala health management in Australia. The KHH has developed a range of fact sheets, protocols and guidelines for koala health and disease investigation work.

Wildlife scientists who are not directly involved in koala health research are based in universities, government agencies and non-government organisations. They may encounter diseased koalas when undertaking field work in koala habitat and may collaborate with wildlife health researchers to sample koalas for disease surveillance or diagnostic purposes. They are also involved in studies where disease is directly linked to ecological processes, such as predation and bushfire.

A range of **land managers** (private land owners, Traditional Owners, industry employees or local government, state and federal government officers) may be responsible for managing land on which koalas live. Traditional Owners of lands play an important role in bringing Traditional Knowledge to scientific practice to maximise outcomes for biodiversity [23].

Other organisations that undertake activities, fundraising and advocacy on behalf of wild koalas are a vital to raising community awareness of koala health and disease issues. Many of these groups also support scientific research and koala rehabilitation efforts. Groups include animal welfare agencies (e.g. RSPCA, International Fund for Animal Welfare), animal conservation agencies (e.g. World Wildlife Fund) and other non-government organisations.

A non-exhaustive list of stakeholders in koala health is included in *Appendix 1*.

3.6 Non-disease threats and their impact on disease

There are many factors other than disease which pose threats to the long-term viability of koalas. Disease is intimately connected to threats such as habitat destruction and fragmentation, habitat-altering natural phenomena (bushfires, drought, flooding), low genetic diversity, climate change and localised overcrowding.

To successfully manage disease risk to the koala, it is necessary to understand the nature of non-disease threats and to develop integrated strategies that simultaneously manage multiple threats in ways which are appropriate to the local situation and scale [13, 24, 25]. For this reason, non-disease threat statements were developed, in consultation with stakeholders, as part of the KDRA (see *Appendix 4 Non-disease Threat Descriptions*). The interactions of non-disease threats with disease are illustrated in a causal flow diagram (Figure 4), developed with stakeholder input. The interactions summarised by the threat statements and the causal flow diagram were considered in the development of disease hazard flow charts, critical control points and disease risk mitigation strategies.

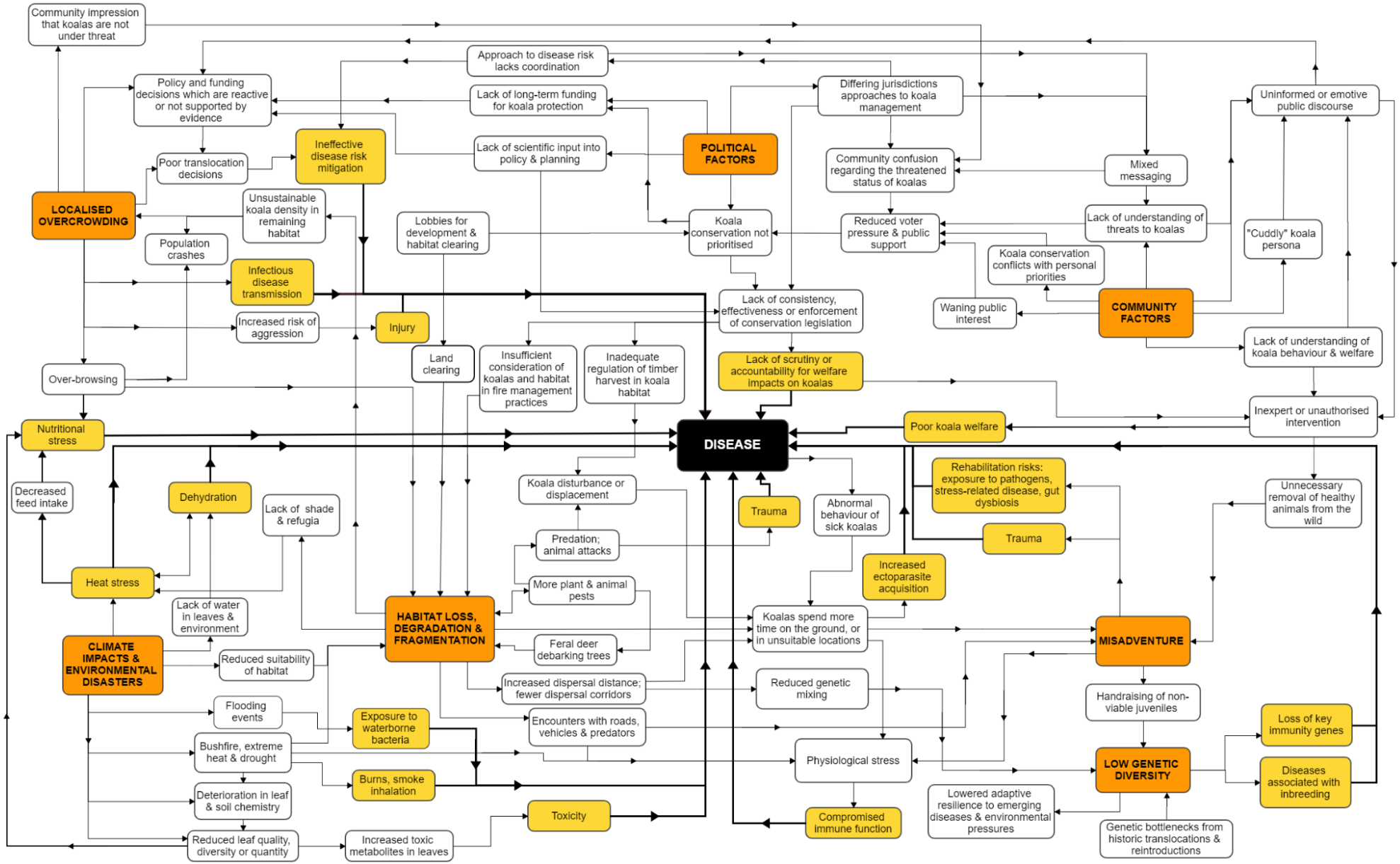

Figure 4 Causal flow chart showing interactions of non-disease threats (orange) with disease in koalas; yellow boxes are proximate causes for disease

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4 Hazard Identification and Refinement

Details of the hazard identification and refinement methodology are in *Appendix 2*.
The hazard identification process identified 91 disease hazards of koalas, listed in Table 3.

Table 3 List of disease hazards of koalas identified through the KDRA process

INFECTIOUS HAZARDS (n=56)
VIRUSES
Barmah Forest virus
Encephalomyocarditis virus
Koala retrovirus (KoRV)
Papillomaviruses
Phascolarctid herpesviruses
Ross River virus
BACTERIA
Acinetobacter lwoffii
Aeromonas hydrophila
Bacteroides spp.
Bordetella bronchiseptica
Burkholderia pseudomallei
Chlamydia spp. *(C. pecorum; C. pneumoniae; novel Chlamydiales)*
Chromobacterium violaceum
Clostridium piliforme
Clostridium septicum
Corynebacterium spp.
Coxiella burnetti
Enterococcus faecalis
Escherichia coli
Helicobacter spp.
Klebsiella spp. (including *K. pneumoniae, K. oxytoca)*
Leptospira spp. (*L. interrogans* serovars)
Morganella morganii
Mycobacteria spp. (including *M. ulcerans*, *M. scrofulaceum)*
Mycoplasma spp.
Nocardia asteroides
Novel *Actinomyces* sp.
Proteus spp.
Pseudomonas aeruginosa
Salmonella spp. (including *S. typhimurium, S. sachsenwald, S. bovismorbificans)*
Serratia marcescens
Staphylococcus spp. (including *S. epidermidis)*
Streptobacillus moniliformis
Streptococcus spp. (including α- and β-haemolytic *Streptococcus* spp.)
Ureaplasma spp.
Yokenella regensburgei
FUNGI
Aspergillus spp.
Candida spp. (including *C. catenulata)*
Coccidioides spp.

Table 3 (continued)

FUNGI (cont.)
Cryptococcus spp. (*C. gattii, C. neoformans)*
Encephalitozoon intestinalis
Ringworm fungi (*Trichophyton mentagrophytes*; *Microsporum gypseum)*
PROTOZOA
Cryptosporidium spp.
Giardia spp.
Toxoplasma gondii
Trypanosoma spp. (including *T. copemani, T. gilletti, T. irwini, T. vegrandis, T. noyesi)*
INTERNAL MACROPARASITES
Bertiella obesa
Durikainema phascolarcti
Nematodes (including *Breinlia mundayi*; *Johnstonema, Marsupostrongylus* & *Ophidascaris* spp.)
EXTERNAL MACROPARASITES
Ctenocephalides spp.
Demodex spp.
Fly strike (*Lucilia cuprina)*
Koalachirus perkinsi
Paralysis ticks (*Ixodes holocyclus, I. cornuatus, I. hirsti)*
Sarcoptic mange (*Sarcoptes scabiei*)
Ticks other than paralysis ticks (including *Haemaphysalis* spp., *Ixodes tasmani)*
NON-INFECTIOUS HAZARDS (n = 35)
DEGENERATIVE
Degenerative joint disease
Degenerative ocular lesions
Hip and shoulder dysplasia
Periodontal disease
Tooth wear
NEOPLASTIC
Neoplasia (includes lymphoid and non-lymphoid neoplasia)
TOXICOSIS
Aluminium toxicosis
Envenomation - snake bite
Fluorosis
DEVELOPMENTAL
Developmental cardiac disease
Developmental urogenital disease
Hydrocephalus
Iris cysts
Malocclusion
Scoliosis and kyphosis
ENVIRONMENTAL
Ballistics trauma
Entanglement trauma
Heat stress
Ocular disease secondary to trauma
Motor vehicle trauma
Predator attack trauma

Table 3 (continued)

ENVIRONMENTAL (cont.)
Reproductive disease secondary to trauma
Thermal burn trauma
Trauma through falling from trees
Trauma from intraspecific aggression
OTHER
Colloid goitre
Diabetes mellitus
Gastrointestinal torsion, intussusception or entrapment
Lithiasis (including struvite; calcium oxalate; uric acid)
Microchip transponder reactions
Oxalate nephrosis
Phytobezoars
OTHER CLINICAL SYNDROMES
Gut dysbiosis (caeco-colic dysbiosis/typhlocolitis syndrome)
Putative KoRV-associated disease syndromes
Wasting syndromes

Appendix 2 shows the detailed information captured during the hazard refinement process and the rationale for hazard prioritisation. The hazard refinement process identified 13 disease hazards for detailed risk assessment, and these are listed in alphabetical order in Table 4.

Table 4 Disease hazards selected for detailed risk assessment

Shortlisted Disease Hazards (in alphabetical order)
Chlamydia spp.
Cryptococcus spp.
Heat stress
Koala retrovirus
Motor vehicle trauma
Neoplasia
Novel *Actinomyces* sp.
Oxalate nephrosis
Phascolarctid herpesviruses
Predator attack trauma
Sarcoptic mange
Thermal burn trauma
Trypanosoma spp.

Three other disease hazards (gut dysbiosis, wasting syndromes and putative KoRV-associated disease syndromes) warranted further discussion due to their potential impact on koala populations. Because they lacked a clear single aetiology and case definition, they did not lend themselves to the formal IUCN risk assessment process. These syndromes are discussed in more detail in *Section 7 Other Disease Hazards.*

5 Risk Assessments for Selected Hazards

Detailed risk assessments were conducted for the 13 selected hazards listed in Table 4. Reviews of current knowledge and literature, that formed the basis for each risk assessment, are provided in *Appendix 5 Hazards for Detailed Risk Assessment – Literature Reviews*.

5.1 *Chlamydia* spp. in Koalas - Risk Assessment

The literature review which supports this risk assessment is in *Appendix 5.1*.

5.1.1 Hazard summary

- *Chlamydia pecorum* (*Chlamydia*) is a widespread pathogen of koalas. Chlamydial infection in koalas may cause disease which is only detectable only using specialist equipment or internal examination [1-4].
- *Chlamydia pneumoniae* infection in koalas is rarely detected and less pathogenic than *C. pecorum* [2, 5, 6]. Several other *Chlamydia*-like bacteria also infect koalas [7, 8], but their significance is unknown.
- Chlamydial disease can cause reduced fertility or infertility in male and female koalas [1, 3, 8, 9], posing significant threats to population viability [10]. Population impact will likely vary depending on other pressures and threats [11-18].
- *Chlamydia* is probably primarily transmitted via sexual contact [1, 19], with direct contact between dam and joey likely to be important in transmission to juveniles [1, 20-23]. Transmission from other species could potentially occur, but its significance to *Chlamydia* epidemiology in koalas is unknown [24-26].
- Prevalence of chlamydial infection and expression of chlamydial disease (chlamydiosis) are variable throughout the koala's geographic range [1, 3, 6, 9, 20, 27-35].
- Pockets of zero prevalence may be present [1, 3, 4, 36], but the factors leading to this circumstance are not well understood. The ubiquitous nature of this organism and the extensive sampling needed to declare freedom of infection in populations means that claims of *Chlamydia*-free status should be accompanied by an indication of the level of certainty of the claim.
- Longitudinal monitoring data suggest that progression from chlamydial infection to disease may be more common than previously thought [28].
- Typical clinical presentations are ocular disease [1, 37-39], urinary tract disease [37, 40-44], reproductive disease [1, 3, 8, 9] or combinations of the three. Disease is characterised by marked inflammation and tissue fibrosis [45] and can have severe welfare implications for affected individuals.
- Chlamydial disease occurs throughout the koala's range [1-3, 5, 6, 9, 27, 30, 32-34, 46, 47], although disease is generally considered less severe in southern koala populations [3, 6, 9, 33, 35].
- Chlamydial disease is initially inflammatory, and chlamydial shedding is likely to be at its greatest in the early phase [28, 45]. Disease progresses in many cases to permanent scarring of the urinary and reproductive tract [41, 42], which can persist without outward signs of disease or chlamydial shedding. Ultrasonography is generally required to detect later phases of urogenital disease [43].
- The development of disease in an individual koala is likely due to a complex combination of host [9, 19, 28, 45, 48-54], pathogen [1, 2, 8, 17, 19, 20, 28, 31, 33, 50,

55, 56], and environmental factors [4, 15, 18, 19, 57, 58], which remain poorly understood and probably vary among populations. Co-infection with other agents [14, 17, 59-63], particularly KoRV [60, 61, 64-68] and herpesviruses [35, 69, 70], potentially also plays a role.

- Effective treatment of chlamydiosis requires hospitalisation and antibiotic therapy. Treated animals released back to the wild may relapse or become reinfected [71]
- The control of *Chlamydia* at the population level, through coordinated programs to capture, treat and release individuals, can be an effective tool for reversing population decline in defined populations [16, 72].
- Vaccination could eventually be a valuable tool for preventing and controlling chlamydial infection and disease [73-84], but further research is needed to identify an effective product.
- For further detail on current knowledge of this hazard, refer to *Appendix 5.1 Chlamydia spp. in Koalas - Literature Review.*

5.1.2 Justification for hazard selection

Chlamydia is a common and widespread pathogen of koalas that can cause severe illness and death [17, 18, 85-88] and may have a significant role in koala population declines by increasing mortality and reducing fertility [10, 16, 58, 89].

5.1.3 Identified gaps in knowledge

- Understanding of chlamydial virulence traits and strain diversity is needed to clarify the importance of genotype to pathogenicity, and to better define what constitutes a "novel" strain for management purposes [3, 6, 9, 35, 90, 91].
- The role of co-infections, particularly KoRV and PhaHV, in predisposing koalas to chlamydial disease and infertility needs to be elucidated [17, 34, 35, 60, 68, 70, 92].
- An understanding of the role of koala genetics in determining immune response to chlamydial infection is needed to improve understanding of host differences in chlamydial susceptibility, disease severity and vaccination response [93].
- The relative importance of chlamydiosis, among other threatening processes, to koala population dynamics has yet to be elucidated over the koala's distributional range [58, 94]. This requires long-term, longitudinal monitoring for chlamydial infection and disease, fecundity and other indices of population viability, in conjunction with comprehensive host, environment and pathogen data [58, 94].
- The capacity for cross-species transmission of *Chlamydia* between koalas and livestock or other wildlife species is incompletely understood [3, 95].
- More evidence-based investigation of treatment regimens and post-release outcomes for chlamydiosis is needed to improve the efficacy of treatment options and release decisions [96-98]. This may involve longitudinal monitoring of koalas after treatment and further pharmacokinetic and clinical efficacy studies of medications commonly used to treat *Chlamydia* infection (antibiotics, anti-inflammatories etc.).

- Further development of non-antimicrobial treatment options, including vaccination against *C. pecorum*, is required.
- Validation of sensitivity and reliability of techniques for detection of *Chlamydia* in scats is needed to assist in the rapid and accurate determination of chlamydial prevalence in free-ranging populations.
- Nationally-agreed guidelines for treatment, triage, assessment and biosecurity in relation to *Chlamydia* infection are needed [99].

5.1.4 Risk assessment

Chlamydia pecorum is the most commonly detected species of *Chlamydia* in sick and injured koalas and is the primary cause of chlamydial disease in this species [27, 39]. For this reason, this risk assessment considered only *C. pecorum.* However, risk mitigation options are also likely to be valid for other *Chlamydia* species.

Figure 5 shows a schematic of the hazard pathways and critical control points (CCPs) identified for this hazard. Critical control points are *key* points in the hazard pathway where risk mitigation methods could be most effective (see *Appendix 2.3 Risk Assessment Methods* for further information). Nineteen CCPs (CCP1-CCP19) were identified across all hazards, but only those applicable to this hazard are described below. See *Section 6 Critical Control Points by Disease Hazard* for a summary of CCPs across all hazards selected for detailed assessment.

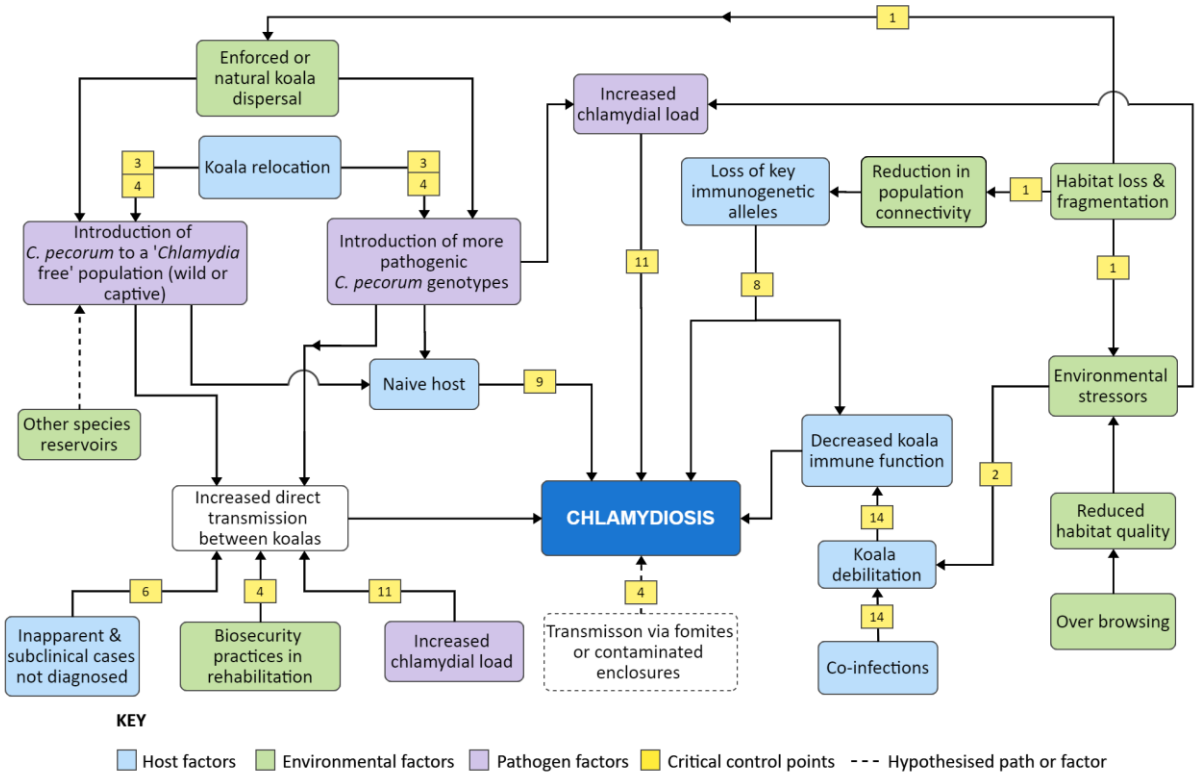

Figure 5 Hazard pathways and critical control points for chlamydiosis in koalas

Critical control points

CCP1 Habitat loss, fragmentation and reduction in quality

Habitat loss and reduction in habitat quality are major environmental stressors due to the koala's reliance on particular tree species for food, shelter and thermoregulation [100, 101]. Habitat fragmentation reduces connectivity between suitable koala habitats, forcing dispersal and potentially contributing to the loss of important genetic alleles in populations that can no longer interbreed [102-104]. Causes include urban expansion, land clearing for production, inappropriate fire management practices, the introduction of pests, weeds and plant pathogens, over-browsing by koalas as a result of local overcrowding, and the habitat-altering effects of climate change [13, 105-110].

The relationship between development of chlamydial disease and habitat factors is complex and is likely to reflect a range of co-factors operating over different scales of time [17, 18].

CCP2 Environmental stressors

Stressors in the koala's environment (in the wild or in captivity) contribute to general debilitation of the host, reduced immune function, and increased susceptibility to disease or severity of disease expression [101, 111-113]. Major environmental stressors for koalas include habitat loss, fragmentation and reduction in quality; nutritional stress; climate change; extremes of weather and disturbance related to human activities [100, 114].

A variety of environmental stressors including overcrowding (in the wild or in captivity), declining food resources and extremes of weather could affect the prevalence of chlamydial disease in koala populations [13-15, 115]. Stress and malnutrition have been implicated in exacerbating chlamydial disease in other species [116-118].

CCP3 Koala relocation

Human-mediated movement of koalas may increase disease risk by introducing pathogens, or new pathogen varieties [119]. This may occur when koalas are brought into rehabilitation or released from rehabilitation (especially if not returned to their point of capture), when captive koalas are transferred between facilities [120], when koalas are translocated from one wild population to another [121], or when habitat corridors are created to reconnect long-separated populations without consideration of disease control.

In particular, relocated koalas infected with *C. pecorum* pose a risk of introducing more pathogenic molecular types to a population or introducing *C. pecorum* to a '*Chlamydia*-free' population [10, 122].

CCP4 Biosecurity practices

Biosecurity practices aim to ensure that infected koalas (or those of unknown infection status) do not pose a risk to other koalas in the population (captive or wild). Biosecurity practices may include quarantine of incoming or outgoing animals, appropriate use of

personal protective equipment, general hygiene, prophylactic treatment and disinfection practices [99, 119].

In rehabilitation, koalas infected with *C. pecorum* may infect other animals if biosecurity practices are inadequate [99, 119]. In the wild, lack of consideration of biosecurity in translocations may lead to introduction or spread of *C. pecorum*.

CCP6 Diagnostics

Insufficient or inadequate diagnostic methods for *Chlamydia*, or poor application of diagnostic tests, may lead to failure to detect *Chlamydia*-infected animals [58], resulting in an increased risk of transmission to uninfected koalas.

CCP8 Genetics

The individual koala may have a genetic predisposition to the development of disease or increased severity of disease.

In particular, koalas that develop more severe chlamydial disease may lack critical alleles that would enable them to mount a more effective immune response [50, 51, 53, 123]. Improving or at least maintaining genetic diversity in koala populations is likely to conserve adaptive potential [124] and encourage the retention of the most robust koala genetic profiles to avoid disease consequences of *Chlamydia* infection.

CCP9 Naïve host

An infectious pathogen may be introduced to a previously unexposed population or a previously uninfected individual.

Introduction of *Chlamydia pecorum,* or novel genotypes, to naïve individuals or populations, may have a detrimental impact on individual health and welfare or population viability [3, 10, 31, 125].

CCP11 Increased pathogen load

An increase in the load of an infectious pathogen that a koala is exposed to, or that a koala carries, influences the severity of disease caused by that pathogen as well as the likelihood of transmission.

The chlamydial load in infected koalas is highest during early infection and declines in chronic infections [28, 45]. Progression of urogenital tract disease (with its associated detrimental effects on koala fertility and welfare) is significantly associated with an increased chlamydial load [28].

CCP14 Concurrent infections and debilitation

Concurrent infections and debilitation can compromise immune function and general health in ways that increase the risk or severity of disease. The pathogenicity of an infectious hazard may be potentiated by co-infections.

Chlamydial disease is likely to be exacerbated by opportunistic infections from a range of microbes [14, 42, 62, 126]. The presence of koala gammaherpesviruses (PhaHV-1 and PhaHV-2) has been associated with infection with *C. pecorum* in both male and female koalas in Victoria [69, 70]. An association between reproductive disease caused by *C. pecorum* and PhaHV co-infection has been reported in SA koalas [34]. Associations between chlamydial disease severity and increased KoRV proviral or viral load have been identified in a number of studies [64-67, 127], although there is currently no clear causative evidence of KoRV inducing more severe chlamydial disease in koalas.

Likelihood assessments

Likelihood of entry and exposure for koalas was considered for the transmission pathways "koala population to koala population" and "other animal population to koala population". *Chlamydia pecorum* is not known to be zoonotic [128, 129], and fomites were not considered a likely major source of transmission, so the "human to koala" and "environment to koala" pathways were not considered. The likelihood of an infected koala causing a hazard to other animals (via their exposure to koalas or koala environments) was also evaluated.

Entry assessment - koalas

Chlamydial infection has been recorded in virtually all wild koala populations [39] and is commonly detected in apparently healthy free-ranging koalas [2, 9, 15, 28, 57, 59, 130]. *Chlamydia pecorum* sequence types identical or very similar to those found in koalas are also present in a range of other species in koala environments, including Australian marsupials, native birds and livestock [24, 25, 32, 131-133]. A small number of koala populations may be *"Chlamydia*-free" [3, 134, 135], but they are commonly found near infected koala populations or other potentially infected species, particularly livestock [32, 133].

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of *C. pecorum* entering, or being present, in a koala population is considered **HIGH**.

Exposure assessment - koalas

Chlamydial infection is likely to be transmitted sexually between koalas [1, 19] with direct contact between dam and joey probably the most important transmission route to juveniles [1, 20-23]. *Chlamydia* can survive outside of the host [136], which may allow for transmission via fomites, but this has not been confirmed.

The proportion of koalas exposed to the bacterium that go on to develop an infection is not known. Prevalence of chlamydial infection is variable throughout the koala's geographic range [1, 3, 6, 9, 20, 27-34], from over 80% in certain populations in Qld [1], Vic [30] and SA [1, 9] to 0% in a few populations [1, 3, 4, 36]. Based on the precautionary principle, the

assessment of exposure likelihood was made on the assumption that *Chlamydia* is present in most, if not all, populations.

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of exposure to *C. pecorum* for an individual koala is considered **HIGH.**

Using the principles of combining entry and exposure likelihood as outlined in *Appendix 2.3 Risk Assessment Methods*, the combined likelihood of entry and exposure of *C. pecorum* for koalas is considered **HIGH**.

Likelihood assessments for other species exposed to infected koalas

Spillover of *C. pecorum* from koalas to other species such as livestock and other wild marsupials has been hypothesised [24, 25]. By the precautionary principle, spillover was considered possible in this assessment, although there are no confirmed reports of this occurring, and it is considered very unlikely to occur.

Using the principles of combining entry and exposure likelihood as outlined in *Appendix 2.3 Risk Assessment Methods*, the combined likelihood of entry and exposure of *C. pecorum* to other species due to infection in koalas is considered **LOW**.

Consequence assessments

Koala population resilience and viability

Prevalence of chlamydial infection in free-ranging koala populations can be over 80% [1, 9, 30], and very few populations have zero prevalence. Not all infected koalas develop disease, and the reported prevalence of chlamydial disease is lower than infection [2, 9, 15, 28, 57, 59, 130]. Disease prevalence reported in free-ranging populations ranges from 4% to 43% [6, 20, 67, 137]. A study in south-east Qld found that 66% of koalas diagnosed with chlamydial infection via PCR progressed to overt disease within 3-4 years [28]. On the precautionary principle, the consequence to population viability was evaluated based on the highest reported figures of >80% prevalence of infection and 44% prevalence of disease.

Chlamydial infection can impact fertility in male and female koalas [1, 3, 8, 9] and free-ranging koala population viability [10, 16, 58, 89]. Modelling studies indicate that eradicating chlamydial infection can be critical to reversing population declines in koalas [11, 16]. However, as with almost all disease states in wild populations, the relative importance of chlamydiosis as a driver of population dynamics is difficult to measure [48, 58] and probably varies across the koala's distribution [94, 138].

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of *C. pecorum* to koala population resilience and viability is considered **MODERATE**.

Koala individual health and welfare

As noted above, not all cases of chlamydial infection progress to disease. However, severe chlamydial disease in koalas is painful, debilitating, and without treatment, can result in death [17, 18, 85-88]. Chlamydial disease accounted for up to 52% of admissions in NSW and Qld rehabilitation facilities and was present in up to 63% of post mortem cases in two SA studies [9, 19, 48, 55, 88].

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of *C. pecorum* to koala individual health and welfare is considered **MAJOR**.

Health and welfare of other species

Exposure to infected koalas (or their environments) has not been reported to lead to chlamydial disease in other species.

Disease due to *C. pecorum* occurs commonly in livestock [139] and is reported occasionally in Australian native marsupials other than koalas [24, 128, 140]. Subclinical infections in livestock are common, but disease manifestations can include conjunctivitis, meningitis and polyarthritis [139]. Disease manifestations in Australian native species are less common, but ocular and possibly urogenital signs have been reported [24, 140].

It is highly unlikely that exposure to an infected koala would have measurable consequences for other species. Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of *C. pecorum* infection to the health and welfare of other species is considered **NEGLIGIBLE**.

Overall risk estimate

The overall risk of *C. pecorum* to koala populations, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **HIGH**.

The overall risk of *C. pecorum* to individual koalas, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **HIGH**.

(Since the consequence of *C. pecorum* in koalas to the health and welfare of other animal species was evaluated as negligible, the estimate of risk for this hazard for the health and welfare of other animals was also considered **NEGLIGIBLE** - see *Appendix 2.3 Risk Assessment Methods*).

This assessment exceeds the acceptable risk thresholds outlined in *Appendix 2.3 Risk Assessment Methods* for koala populations and for individual koalas. Therefore, risk management for *C. pecorum* is recommended for both koala populations and individual koalas.

Level of confidence in risk assessment

Factors associated with koala-to-koala transmission of *Chlamydia* are well recognised and well-studied. There is information on *Chlamydia* prevalence in most populations. The capacity for transmission from other species to koalas and vice versa is unknown. Overall, the level of confidence in the likelihood assessment is **HIGH**.

The impact of *C. pecorum* on population viability is not well understood in all populations throughout the koala's range and details of population impacts are not widely documented in peer-reviewed literature [16, 58]. Therefore, the level of confidence in the consequence assessment for koala populations is **MEDIUM**.

The clinical manifestations of chlamydial disease are well studied and well recognised. Therefore, the level of confidence in the consequence assessments for individual koalas is **HIGH**.

Overall, the confidence in the risk estimate for *C. pecorum* is considered **HIGH**.

5.1.5 Risk mitigation options

The following risk mitigation measures have been identified for *C. pecorum*. Further information and justification can be found in the *Treatment* and *Prevention and control* sections of the relevant literature review chapter. Risk mitigation options were assessed for both effectiveness and feasibility during KDRA Stakeholder Workshops, and are listed here in descending order of effectiveness and feasibility. Note: Risk mitigation options are possibilities for risk mitigation and should not be confused with recommendations for action (which are listed below).

- Early diagnosis, triage and treatment (or euthanasia) of diseased individuals (CCP6, CCP9, CCP11 and CCP14).
- Implement biosecurity practices specific to *Chlamydia* for koalas entering rehabilitation (CCP4).
- Develop protocols for robust, systematic testing to accurately identify *Chlamydia*-positive and -negative individuals and reduce the risk of transmission to uninfected individuals (CCP6, CCP9, CCP11 and CCP14).
- Reduce the risk of introducing *Chlamydia*, or novel genotypes, to wild populations, by adopting pre-release testing protocols to ensure that koalas are pathogen negative, and clinical signs of active disease are controlled before they are released to the wild (CCP6, CCP9, CCP11 and CCP14).
- Practise barrier hygiene between koalas of different *Chlamydia* status (CCP4).
- Implement biosecurity practices to avoid spread of *Chlamydia* when conducting fieldwork on wild koalas e.g. dedicated equipment, disinfection (CCP6, CCP9, CCP11 and CCP14).
- Re-vegetation, restoration and preservation of habitat, including in urban landscapes (CCP1).

- Minimise stress in koalas being translocated (CCP3, CCP4 and CCP9).
- Incorporate *Chlamydia* vaccination of koalas (when available) into rehabilitation settings to reduce severity of disease and assist in clearing infection (CCP11).
- Repopulate viable habitat with koalas free of *C. pecorum* (CCP3, CCP4 and CCP9).
- Establish biosecurity and koala relocation protocols to prevent the introduction of *Chlamydia* into populations with low or zero prevalence (CCP3, CCP4 and CCP9).
- Prevent cross-contamination through appropriate disinfection, personal protective equipment and equipment use (CCP4).
- Maintain *Chlamydia*-negative captive populations of koalas through quarantine and diagnostic testing of new arrivals and routine diagnostic testing of existing captive koala populations (CCP3, CCP4, CCP6, CCP9 and CCP11).
- Incorporate vaccination (once available) into population management to reduce *Chlamydia* prevalence, load and severity (CCP11).
- Incorporate *Chlamydia* vaccination of koalas (when available) into captive management to reduce likelihood of disease development (CCP11).
- Strengthen regulatory controls against habitat clearing in koala habitat and dispersal corridors (CCP1).
- Support genetic diversity in koala populations to encourage the retention of the most robust koala genetic profiles to enable effective immune response and avoid disease consequences of *Chlamydia* infection (CCP8).
- Minimise concurrent infections, debilitation and other stressors in the captive environment, to reduce the risk of pathogenic consequences in koalas infected with *Chlamydia* (CCP2 and CCP14).
- Minimise concurrent infections, debilitation and other environmental stressors (e.g. predators, disturbance related to human activities) in individual free-living koalas and populations, to reduce the risk of pathogenic consequences for koalas infected with *Chlamydia* (CCP2 and CCP14).
- Minimise concurrent infections, debilitation and other stressors in the rehabilitation environment, to reduce the risk of pathogenic consequences in koalas infected with *Chlamydia* (CCP2 and CCP14).

5.1.6 Recommendations

Recommendations for *Chlamydia* are grouped as “top priority” and “next priority” as determined through consultation during the KDRA Stakeholder Workshops.

All general recommendations listed in *Section 1.6.2* apply to *Chlamydia*.

Hazard-specific recommendations

The following recommendations are specific to this hazard:

Top priority recommendations specific to Chlamydia:

1.1 Develop nationally-agreed protocols for triage and assessment of koalas with *Chlamydia* infection, including criteria for consideration of euthanasia.

1.2 Support pharmacokinetic and clinical studies for treatment of *Chlamydia* infection (antibiotics, anti-inflammatories etc).

1.3 Develop nationally-agreed guidelines for diagnostic testing for *Chlamydia.*

1.4 Develop *Chlamydia*-specific biosecurity protocols for koalas in free-living, captive and rehabilitation environments.

Next priority recommendations specific to Chlamydia:

1.5 Improve understanding of the link between stress and chlamydial disease and improve communication of definition of "stress".

1.6 Support research and development of vaccines against *Chlamydia* in koalas

1.7 Develop nationally-agreed protocols for treatment for chlamydiosis.

1.8 Continue investigations to determine the importance of chlamydial genotypes to pathogenicity.

1.9 Incorporate *Chlamydia* risk assessment and mitigation into koala relocation protocols, including general biosecurity practices, pre-release clinical evaluation & *Chlamydia* testing.

1.10 Develop nationally-agreed protocols for use of vaccination as a tool for controlling *Chlamydia*.

1.11 Continue investigations to determine importance of co-morbidities to pathogenicity of *Chlamydia.*

1.12 Share information with rehabilitators on the biosecurity risks of *Chlamydia* transmission in rehabilitation.

5.1.7 References

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5.2 Koala Retrovirus – Risk Assessment

The literature review which supports this risk assessment is in *Appendix 5.2.*

5.2.1 Hazard summary

- Koala retrovirus (KoRV) is an RNA virus that replicates (like other retroviruses) by inserting DNA copies of itself (proviruses) into the genome of host cells [1, 2].
- KoRV is a relatively young retrovirus that exists in both endogenous and exogenous forms [3, 4]. Endogenous KoRV is incorporated into koala gamete cells and therefore is inherited genetically. Exogenous KoRV integrates into the genome of somatic (non-reproductive) cells, and is not inherited by the next generation [1]. Endogenous KoRV-A retains many features commonly associated with pathogenesis by exogenous retroviruses [5, 6].
- The complete KoRV genome consists of three genes (*gag*, *pol* and *env*). KoRV variants (KoRV-A to KoRV-M) are based on phylogenetic groupings of the *env* gene [7]. The *pol* gene is required for transcription [1] and KoRV types that lack all or part of the *pol* gene are not replication-competent [8-10].
- KoRV-A occurs both endogenously and exogenously and is replication-competent [8]. It is endogenous in 100% of northern koalas [6, 11] but in southern populations, endogenous KoRV-A has not been detected [6, 12, 13].
- All KoRV variants other than KoRV-A are exogenous and are only present in koalas that also harbour KoRV-A [11, 14-16]. Prevalence and distribution of exogenous variants appear variable [5, 16-24]. Some exogenous variants are not replication-competent [2, 10, 11, 25, 26].
- Transmission of exogenous KoRV variants appears to occur through close contact, most likely mother-to-offspring [14, 24, 27, 28] though some experts dispute this.
- Defective retroviral elements known as recKoRV appear to be endogenous and are widespread in koala populations, including southern populations where endogenous KoRV has not been detected [8].
- KoRV might increase koala susceptibility to disease by increasing mutagenic load, thus predisposing koalas to neoplastic disease [29] and by causing immune modulation [30-32], which could increase disease susceptibility of the koala and severity of disease expression for a range of disease hazards.
- Various KoRV traits (such as viral load, proviral load, variant presence or load and *pol* presence or load) have been associated with a range of disease states and co-infections in koalas [15, 18, 20, 21, 33-42]. It is generally considered likely that all of these variables actually reflect increased viral replication in the host. In most cases, it is unclear whether the relationship is causative (i.e. that KoRV causes disease) or secondary (i.e. disease permits or induces amplification of KoRV).
- It is unclear if replication-competent KoRV variants differ in their ability to cause disease.

- Presence in both endogenous and exogenous forms, and replication competence of endogenous forms, indicate a relatively new host-pathogen relationship that is likely to cause morbidity and mortality until equilibrium is achieved. The ability of the koala species to survive that process depends in part on mitigating mortality from other threats, while maintaining the species adaptive potential though sufficient population size and genetic diversity.
- For further detail on current knowledge of this hazard, refer to *Appendix 5.2 Koala Retrovirus - Literature Review.*

5.2.2 Justification for hazard selection

KoRV is retained for risk assessment because of its potential to cause or exacerbate disease states in koalas.

5.2.3 Identified gaps in knowledge

- Associations between KoRV and other disease hazards require further investigation, particularly with neoplasia, chlamydiosis, koala herpesviruses, *Trypanosoma* spp., novel *Actinomyces* sp., and general debilitative states that are considered the hallmarks of the "KoRV koala" (see also *Section 7.1 Clinical Syndromes with Undefined or Multiple Aetiologies*). In most cases, it remains to be determined whether KoRV plays a causative role in disease manifestations or susceptibilities, or if conversely these other hazards alter KoRV traits in the affected individual.
- Recommended methods for testing and measuring KoRV status in koalas to inform risk mitigation efforts need to be confirmed [42].
- The transmissibility and transmission mechanisms of exogenous KoRV variants requires investigation.
- Further investigation of KoRV profiles of southern koala populations is needed, to determine the prevalence of recKoRV in populations previously thought to be "KoRV free"; to resolve contradictory evidence over presence or absence of variants other than KoRV-A; and to understand the drivers for regional differences in KoRV load.
- The hypothesis that recKoRV elements protect southern koalas from replication-competent KoRV endogenisation requires investigation.
- More comprehensive and coordinated knowledge of the KoRV status of koalas in captivity is needed, including recommendations on how best to quantify and manage KoRV status in captive breeding and insurance populations.
- A more complete assessment of the potential for cross-species transmission of KoRV is required, including zoonotic transmission.
- Regimens for treatment of koalas with KoRV, including anti-retroviral drug options and pharmacokinetics, require investigation.
- Further investigation of the viability and safety of vaccination for the treatment, prevention and control of KoRV is needed.

5.2.4 Risk assessment

Figure 6 shows a schematic of the hazard pathways and critical control points (CCPs) identified for this hazard. Critical control points are defined as *key* points in the hazard pathway where risk mitigation methods could be most effective (see *Appendix 2.3 Risk Assessment Methods* for further information). Nineteen CCPs (CCP1-CCP19) were identified across all hazards, but only those applicable to this hazard are described below. See *Section 6 Critical Control Points by Disease Hazard* for a summary of CCPs across all hazards selected for detailed assessment.

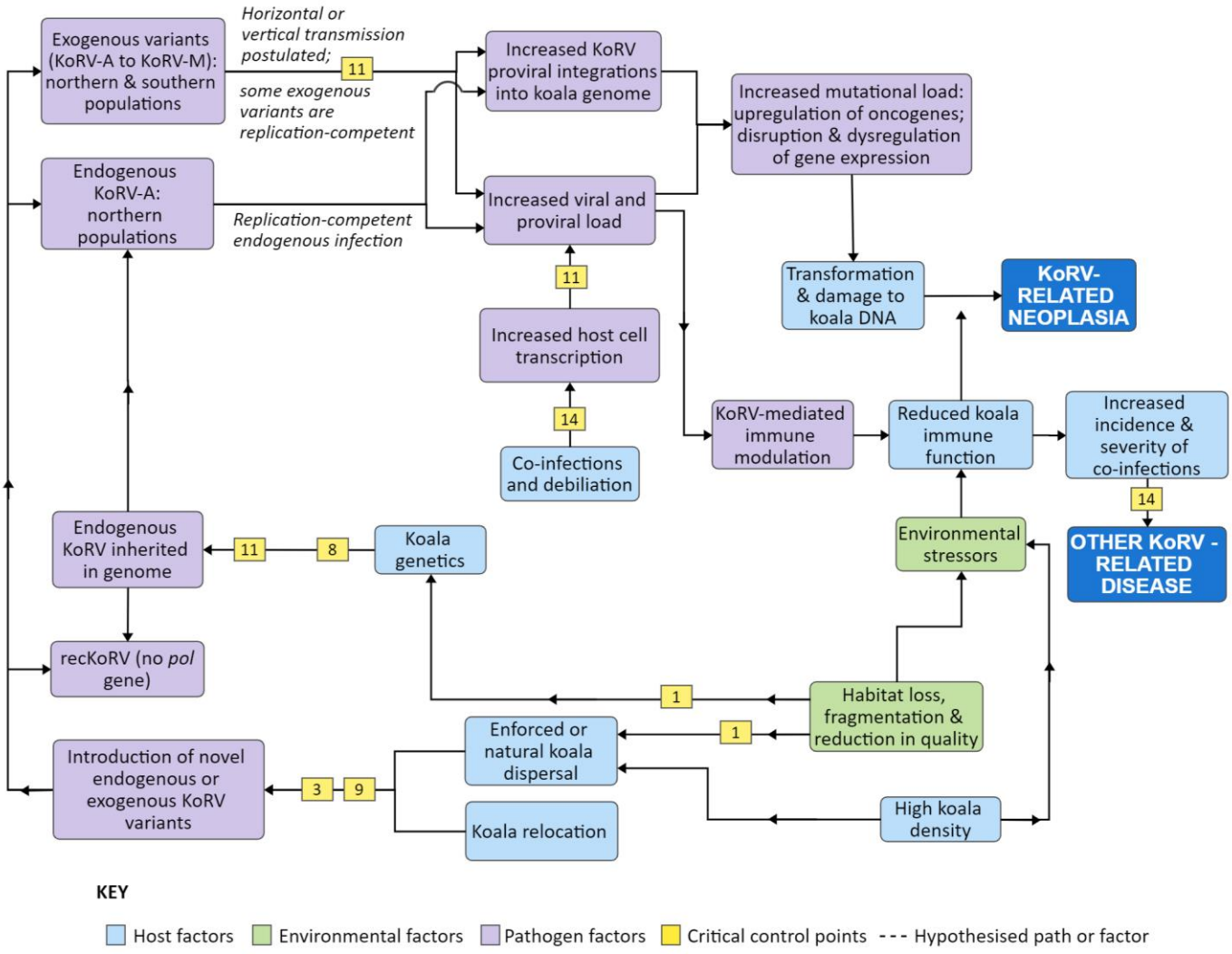

Figure 6 Hazard pathways and critical control points for KoRV

Critical control points

CCP1 Habitat loss, fragmentation and reduction in quality

Habitat loss and reduction in habitat quality are major environmental stressors due to the koala's reliance on particular tree species for food, shelter and thermoregulation [43, 44]. Habitat fragmentation reduces connectivity between suitable koala habitats, forcing dispersal and potentially contributing to the loss of important genetic alleles in populations

that can no longer interbreed [45-47]. Causes include urban expansion, land clearing for production, inappropriate fire management practices, the introduction of pests, weeds and plant pathogens, over-browsing by koalas as a result of local overcrowding, and the habitat-altering effects of climate change [48-54].

In particular, habitat loss and fragmentation limits effective population size [45-47], increasing the likelihood of genetic establishment of deleterious KoRV integrations, or of heritable traits which encourage KoRV to escape containment, so that extinction may be reached before host adaptation can be achieved.

CCP3 Koala relocation

Human-mediated movement of koalas may increase disease risk by introducing pathogens, or new pathogen varieties [55]. This may occur when koalas are brought into rehabilitation or released from rehabilitation (especially if not returned to their point of capture), when captive koalas are transferred between facilities [56], when koalas are translocated from one wild population to another [57], or when habitat corridors are created to reconnect long-separated populations without consideration of disease control.

In particular, *pol*-positive koalas (koalas infected with replication-competent KoRV) moved to *pol*-negative populations could pass on replication-competent KoRV to offspring and descendants within the new population [1, 3, 14, 58]. Relocation of individuals may pose a risk of introducing novel exogenous variants to a naïve population, if exogenous transmission occurs [14, 23, 24, 59].

CCP8 Genetics

The individual koala may have a genetic predisposition to the development of disease or increased severity of disease. Improving or at least maintaining genetic diversity in koala populations is likely to encourage the retention of the most robust koala genetic profiles to avoid disease consequences of KoRV and facilitate virus-host co-evolution.

Based on fundamental dynamics of recessive genetic traits, inherited KoRV integrations are likely to become fixed or more readily expressed if inbreeding increases [45-47]. In particular, inherited KoRV integrations in the koala genome are associated with increased neoplasia risk to koalas [20, 22], and may be responsible for a hereditary pattern for some neoplastic conditions [60].

CCP9 Naïve host

An infectious pathogen may be introduced to a previously unexposed population or a previously uninfected individual.

Replication-competent (*pol*-positive) KoRV-A has a prevalence of 100% in northern koalas [31] but appears to be absent in its endogenous form from southern populations [6, 12, 13], where competent KoRV-A behaves as an exogenous virus and endogenous *pol*-negative recKoRV appears widespread [8]. The introduction of replication-competent KoRV into the

genome of southern populations (via breeding between *pol*-positive and *pol*-negative koalas) could increase the risk of KoRV-related disease in southern populations and potentially increase the risk of KoRV endogenization.

Exogenous *env* gene variants appear to vary in prevalence throughout the koala's distribution [5, 16-24]. There may be the potential for transmission of new variants into a population via close contact between koalas [23, 59]. The likelihood and impact of this is not understood.

CCP11 Increased pathogen load

An increase in the load of an infectious pathogen that a koala is exposed to, or that a koala carries, influences the severity of disease caused by that pathogen as well as the likelihood of transmission.

Associations between disease states and KoRV viral and proviral load have been identified in many studies [20, 33, 34, 36, 38, 59, 61]. The variety of associations between KoRV traits and disease states suggests that disease is most associated with escape and proliferation of KoRV in any competent form [23].

CCP14 Concurrent infections and debilitation

Concurrent infections and debilitation can compromise immune function and general health in ways that increase the risk or severity of disease. The pathogenicity of an infectious hazard may be potentiated by co-infections.

In particular, koala host cells that are stimulated by inflammation to increase transcription or proliferate (in this case as a result of pathogen infection or general debilitation of the host) likely increase KoRV viral and proviral load [62], resulting in more opportunities for the pathogenic effects of KoRV to be manifest in the host. Host-pathogen co-evolution requires resilient populations. Additional disease threats increase risk of local host extinction occurring before co-evolutionary equilibrium between KoRV and the host [63] can be achieved.

Approach to assessment of KoRV

Likelihood and consequence were assessed only for replication-competent (*pol*-positive) KoRV (hereafter called "*pol* KoRV") in both its exogenous and endogenous forms. RecKoRV, and many exogenous KoRV variants, are not replication-competent and in the absence of *pol* KoRV should be capable of only limited disruption of the koala genome [2, 10], which may limit their pathogenicity.

Likelihood assessments

There is a clear disparity between the prevalence of *pol* KoRV in northern and southern koala populations [5, 19, 37, 64] which affects the assessment of likelihood. For this reason, separate likelihood assessments have been made for northern and southern populations.

Entry assessment

The likelihood of *pol* KoRV entering or being present in a koala population was considered only for the transmission pathway of "koala population to koala population", as KoRV is not known to be acquired from the environment or present in human or other animal species.

Endogenous (inherited) *pol* KoRV has been detected in 100% of northern koalas [5, 6]. In contrast, endogenous *pol* KoRV is absent in southern populations [6, 12, 13] and would only enter via interbreeding with northern koalas. This would require human-assisted movement of koalas, or significant increases in the geographic spread of koalas, as northern and southern populations currently have minimal overlap in geographic distribution [50]. However, exogenous *pol* KoRV is present with variable prevalence in both northern and southern populations [5, 16-24].

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of *pol* KoRV entering, or being present in northern populations is considered **HIGH**.

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of *pol* KoRV entering, or being present, in a southern koala population is considered **HIGH**.

Exposure assessment

The likelihood of exposure to *pol* KoRV was only considered for the "koala-to-koala" transmission pathway, as KoRV is not considered to be present in the environment, or in human or other animal species.

An individual koala acquires endogenous *pol* KoRV through Mendelian inheritance; the transmissibility of exogenous *pol* KoRV has not been established. *Pol* KoRV has been detected in 100% of northern koalas and is endogenised in northern populations (although exogenous *pol* KoRV is also present). Exogenous *pol* KoRV is present with variable prevalence in southern populations and its transmissibility is not confirmed. Endogenous *pol* KoRV has not been detected in southern populations [8].

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of exposure to *pol* KoRV in northern populations is **HIGH**.

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of exposure to *pol* KoRV in southern koala populations is **MODERATE**.

Using the principles of combining entry and exposure likelihood outlined in *Appendix 2.3 Risk Assessment Methods*, the combined likelihood of entry and exposure for *pol* KoRV in northern populations is **HIGH**. The combined likelihood of entry and exposure to *pol* KoRV in southern populations is **MODERATE**.

Consequence assessments

As *pol* KoRV is not considered a hazard for humans or other animal species, the consequence of *pol* KoRV infection in other species, including humans, has not been evaluated.

Although disease manifestations associated with KoRV are considered more significant in northern than southern populations, there are also associations between presence of *pol* KoRV and disease in southern koalas [37] and there is no clear evidence that southern koalas are intrinsically less susceptible to the detrimental effects of KoRV than their northern counterparts. Therefore, consequence assessments for *pol* KoRV for individual koalas and populations were considered to be the same in northern and southern koalas.

Koala population resilience and viability

The consequences of *pol* KoRV infection on koala populations are not clear. There are no reliable estimates of the prevalence of KoRV-related disease in KoRV populations. Fertility and mortality rates in koala populations might be negatively affected by *pol* KoRV status as this might result in increased prevalence and severity of neoplasia and of infectious diseases such as chlamydiosis [15, 18, 20, 21, 33-41, 59, 61]. The precautionary principle dictates that we assume that *pol* KoRV does have a causal influence on these disease states.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of *pol* KoRV to koala population resilience and viability in northern and southern populations is considered **MODERATE**.

Koala individual health and welfare

The consequences of *pol* KoRV infection in individual koalas are not clear. KoRV probably increases susceptibility to neoplasia [29], and might influence development or increased severity of many other disease states [15, 18, 20, 21, 33-41, 59, 61]. These outcomes could lead to significant illness or death, or severe welfare impacts in individual koalas. The precautionary principle dictates that we assume that *pol* KoRV does have a causal influence on the disease states outlined above. Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of *pol* KoRV infection to individual koala health and welfare is considered **MODERATE**.

Overall risk estimate

The overall risk of *pol* KoRV infection to northern koala populations, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **HIGH**.

The overall risk of *pol* KoRV infection to individual northern koalas, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **HIGH**.

The overall risk of *pol* KoRV infection to southern koala populations, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **MODERATE**.

The overall risk of *pol* KoRV infection to individual southern koalas, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **MODERATE**.

These assessments exceed the acceptable risk thresholds as outlined in *Appendix 2.3 Risk Assessment Methods* for both koala populations and individual koalas. Therefore, risk management for *pol* KoRV infection is recommended for both northern and southern koala populations.

Level of confidence in risk assessment

The confidence in the entry assessment is **HIGH**, as there is considerable data on the prevalence of *pol* KoRV infection in free-living northern and southern koala populations. The confidence in the exposure assessment is **MEDIUM** as there are uncertainties about the modes and effectiveness of *pol* KoRV transmission between koalas. The confidence in the consequence assessment for KoRV, for both individuals and populations, is **LOW** as there are many gaps in knowledge regarding the pathogenicity and initiating factors for KoRV-related health issues.

Overall, the confidence in the risk estimate for KoRV is **LOW**.

5.2.5 Risk mitigation options

The following risk mitigation measures have been identified for KoRV. Further information and justification can be found in the *Treatment* and *Prevention and control* sections of the relevant literature review chapter. Approaches to risk mitigation of KoRV are drawn from the currently limited knowledge base. Risk mitigation options were assessed for both effectiveness and feasibility during KDRA Stakeholder Workshops, and are listed here in descending order of effectiveness and feasibility. Note: Risk mitigation options are possibilities for risk mitigation and should not be confused with recommendations for action (which are listed below).

- Test koalas for KoRV variants and select those for relocation based on the number of KoRV variants detected, to minimise the risk of introducing novel exogenous variants to a naïve population.
- Minimise breeding from koala populations or family lines with a high prevalence of neoplasia or other disease states recognised to be potentially KoRV-associated (e.g. severe chlamydiosis, wasting syndrome, persistent or multiple opportunistic infections) to avoid heritable deleterious KoRV integrations, or other genetic traits that allow KoRV to “escape” containment and interfere with cell function.
- Preferentially breed from koalas with the lowest number of replication-competent exogenous variants, to minimise the spread of exogenous variants through populations.
- Select individuals with lower KoRV viral loads for breeding and translocation, and avoid breeding and translocation of koalas with high viral loads, so that koalas have the most robust genetic profiles for avoiding disease consequences of KoRV.

- Use of vaccination against KoRV in koalas (when available) to develop and maintain populations free from endogenous KoRV-A; reduce KoRV viral and proviral loads (and hence associated disease risk to the individual koala) and reduce risk of exogenous transmission (if this occurs) to in-contact koalas.
- Strengthen regulatory controls against habitat clearing and road development in koala habitat and dispersal corridors.
- Identify *pol*-negative captive and free-living southern koala populations, and protect them from the entry of replication-competent KoRV by managed isolation of these populations, to prevent breeding with *pol*-positive koalas.
- Treat dams raising joeys with anti-retroviral medication to reduce the risk of exogenous KoRV transfer to the joey.
- Prevent local extinctions from other causes to enable co-evolution of KoRV to continue with the minimum of impact on koala health and population resilience.
- Minimise concurrent infections, debilitation and other environmental stressors (e.g. predators, disturbance related to human activities) in individual koalas and populations to reduce the potential risk of KoRV-associated immunosuppression and to reduce stimulation of koala host cells that could increase cell transcription or proliferation and lead to increased KoRV viral and proviral load resulting in more opportunities for any pathogenic effects of KoRV to arise.
- Use anti-retroviral medication to treat individual koalas with persistently high viral and proviral KoRV loads, to reduce the likelihood of disease development.

5.2.6 Recommendations

Recommendations for KoRV are grouped as “top priority” and “next priority” as determined through consultation during the KDRA Stakeholder Workshops.

All general recommendations listed in *Section 1.6.2* apply to KoRV.

Hazard-specific recommendations

The following recommendations are specific to this hazard:

Top priority recommendations specific to KoRV:

2.1 Continue research into KoRV with a focus on determining the extent to which it causes disease. This will require a combination of longitudinal and *in vitro* studies to determine causation, and field studies to determine contribution to disease outcomes, relative to other drivers of disease.

2.2 Define thresholds or consistent methodologies for quantifying proviral and viral KoRV load and use these to develop consistent protocols to enable meaningful incorporation of KoRV status into koala management.

2.3 Develop nationally-agreed guidelines for biosecurity, control and prevention of KoRV risk in the management, breeding and movement of free-ranging and captive koalas.

Prevention and control strategies should be revised regularly, given the rapid rate of development of knowledge of KoRV.

Next priority recommendations specific to KoRV:

2.4 Support increased testing and improved data sharing between captive koala populations to allow an evidence-based, scientifically coordinated approach to managing KoRV status of Australia's captive breeding koala population.

5.2.7 References

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5.3 Heat Stress in Koalas - Risk Assessment

The literature review which supports this risk assessment is in *Appendix 5.3*.

5.3.1 Hazard summary

- Heat stress has been reported as a cause of morbidity and mortality in koalas across their geographic range [1-4].
- Heat stress can occur in koalas when the ambient temperature exceeds the upper limit of their thermoneutral zone (24.5^{o}C) and becomes more apparent when ambient temperature exceeds 35^{o}C [5].
- Cooler night temperatures allow koalas to dissipate the body heat they accumulate during the day; warm night temperatures inhibit this process, and their body temperature may rise sequentially over several hot days and nights [5].
- Koalas use physiological cooling strategies such as sweating, panting and peripheral vasodilation to dissipate heat [5, 6]. They also use behavioural cooling strategies such as seeking cooler refugia within their habitat, adapting their body posture and increasing free water intake to offset heat accumulation [7-10].
- Climate change is likely to increase the frequency, intensity and duration of heat events in Australia [11, 12].
- Koalas have a greater chance of surviving heat stress if it is identified and treated in the early stages, and before it progresses to severe stages of illness with multiple organ involvement [13].
- During heat events, increasing the availability of cooler microclimates and providing strategic access to free water may reduce the effects of increased ambient temperature, but are unlikely to fully mitigate them [13].
- Using weather forecasts to predict heat event risk for koalas, as occurs for other heat-susceptible wildlife such as flying-foxes [14], may help to manage the impact of these events on koala populations.
- For further detail on current knowledge of this hazard, refer to *Appendix 5.3 Heat Stress in Koalas - Literature Review*.

5.3.2 Justification for hazard selection

Heat stress has been reported as a cause of morbidity and mortality in koalas across their geographic range, therefore this hazard has been retained for risk assessment.

5.3.3 Identified gaps in knowledge

- Documented reports and protocols for clinical signs, triage, treatment, survival rates and prognostic indicators of heat stress in koalas are lacking, even though heat stress is a relatively common presentation in koalas.
- Effective and efficient ways to reduce the risks of heat stress in free ranging koala populations need to be developed.

- More information is needed on thermal tolerance in koalas (as has been developed for flying-foxes in Australia). This would allow development of a koala heat stress prediction tool, based on weather forecasting.
- Information is needed on differences in physiology between northern and southern koalas and whether genetic management of koala populations for heat tolerance is a viable management tool.

5.3.4 Risk assessment

Figure 7 shows a schematic of the hazard pathways and critical control points identified for this hazard. Critical control points (CCPs) are defined as *key* points in the hazard pathway where risk mitigation methods could be most effective (see *Appendix 2.3 Risk Assessment Methods* for further information). Nineteen CCPs (CCP1-CCP19) were identified across all hazards, but only those applicable to this hazard are described below. See *Section 6 Critical Control Points by Disease Hazard* for a summary of CCPs across all hazards selected for detailed assessment.

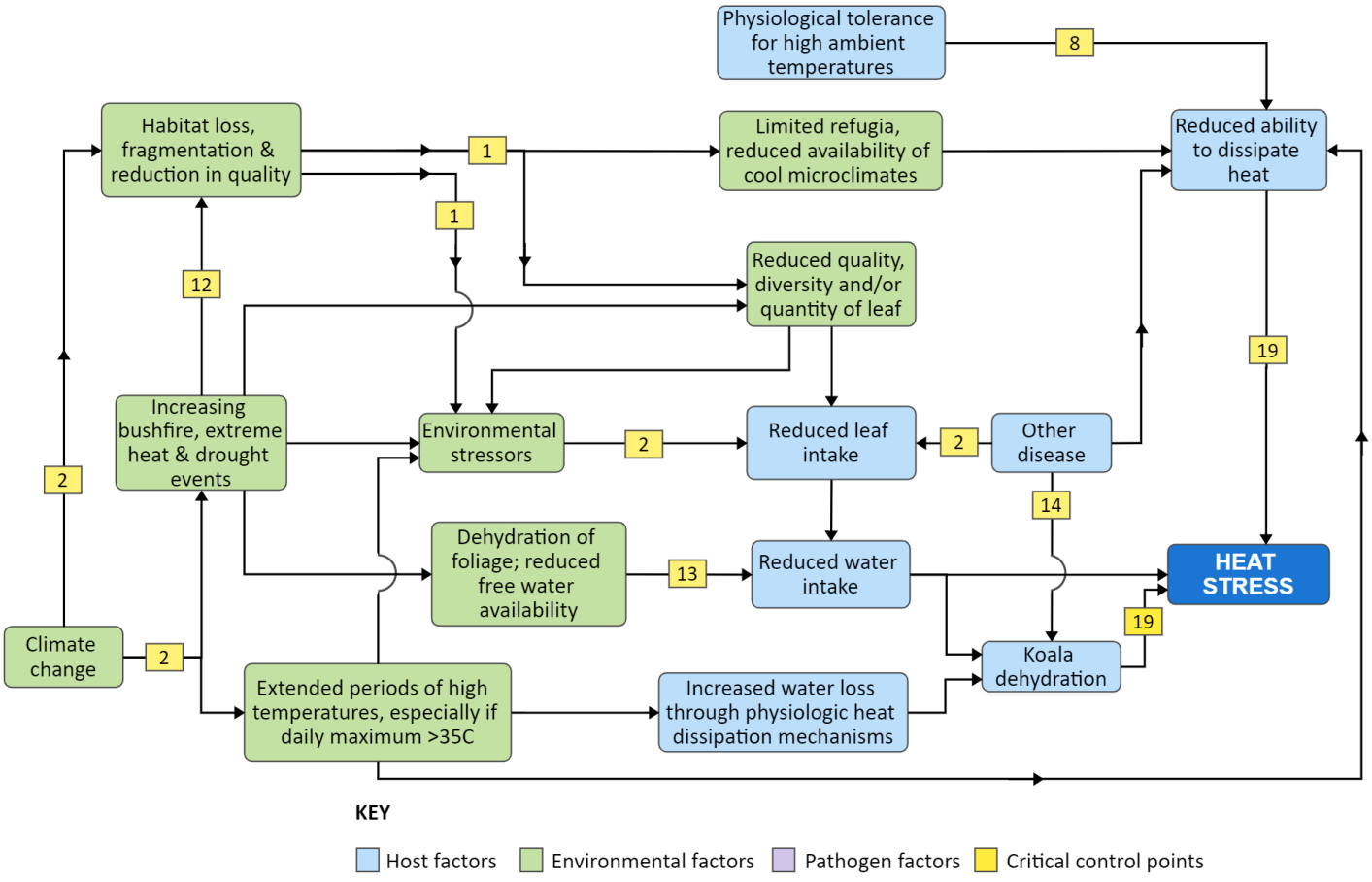

Figure 7 Hazard pathways and critical control points for heat stress in koalas

Critical control points

CCP1 Habitat loss, fragmentation and reduction in quality

Habitat loss and reduction in habitat quality are major environmental stressors due to the koala's reliance on particular tree species for food, shelter and thermoregulation [1, 15]. Habitat loss, reduction and fragmentation reduce connectivity between suitable koala habitats. The resultant loss of refugia for koalas increases the risk of dehydration and exposure to high ambient temperatures [10, 16, 17], which can promote the development of heat stress. Habitat loss and reduction of habitat quality lead to reduced quality, diversity and quantity of leaf for koala consumption [16, 17], causing nutritional stress, decreasing leaf intake and reducing the koala's hydration status.

Causes include urban expansion, land clearing for production, inappropriate fire management practices, the introduction of pests, weeds and plant pathogens, over-browsing by koalas as a result of local overcrowding, and the habitat-altering effects of climate change [18-24].

CCP2 Environmental stressors

Stressors in the koala's environment (in the wild or in captivity) contribute to general debilitation, reduced immune function and increased susceptibility to disease or severity of disease expression [1, 2, 25, 26]. Major environmental stressors for koalas include habitat loss, fragmentation and reduction in quality; nutritional stress; climate change; extremes of weather; and disturbance related to human activities [15, 27].

Koalas obtain about 75% of their water intake from foliage [28]. A reduction in food (and therefore water) intake due to ill health, injury or other stress, may increase the risk of dehydration (which in itself is a source of physiological stress) [27], and reduce heat dissipation through evaporative means.

CCP8 Genetics

An individual koala, or koala populations may have a genetic susceptibility or resistance to developing heat stress [29]. Improving or at least maintaining genetic diversity in koala populations is likely to conserve adaptive potential [30] and encourage the retention of the most robust koala genetic profiles that favour thermal tolerance.

CCP12 Fire management practices

Inadequate planning, inappropriate methodology or flawed execution of fire management practices may contribute to habitat loss and reduction of habitat quality, reducing refugia options for koalas during heat events [31, 32].

CCP13 Reduced water intake

In hot weather, koalas may experience reduced water intake due to lower leaf moisture content and lower free water availability (artificial or natural sources) for drinking [18, 33].

Reduced water intake may hamper physiologic heat dissipation mechanisms and cause dehydration [10, 33].

CCP14 Concurrent infections and debilitation

Concurrent infections and debilitation can compromise immune function and general health in ways that increase the risk or severity of disease. Any disease process that inhibits convection, evaporative or behavioural means of thermoregulation would likely decrease the koala's ability to cope with elevated ambient temperatures. Compromised immunity, hydration status and general health may increase the risk and severity of heat-related illness [13, 34].

CCP19 Emergency response to heightened risk

In situations where environmental conditions are associated with increased disease threats (e.g. bushfires, high ambient temperatures), *in situ* preparedness and response activities may significantly reduce risk to koalas. Actions may include community awareness and behaviour change campaigns (e.g. [35, 36]) as well as advance planning for emergencies, and deployment of rapid response teams (e.g. [37, 38]).

Likelihood assessments

Heat stress is a non-infectious hazard and therefore likelihood assessments were not made in relation to humans or other species.

Ambient temperatures above 30°C commonly occur over much of the koala's natural range [39]. Loss of habitat quality and complexity makes koalas more vulnerable to heat stress events when they occur [18, 40]. The frequency and intensity of heat events in koala habitat is likely to increase with climate change [21, 41]. There are no accurate data on the prevalence of heat stress in koala populations that are experiencing high ambient temperatures. Not all areas of the koala's natural distribution experience extremes of temperature likely to result in heat stress.

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of a koala experiencing prolonged ambient temperatures sufficient to induce heat stress, during its lifetime is considered **MODERATE**.

Consequence assessments

Heat stress is a non-infectious hazard and therefore consequence assessments were not made in relation to humans or other species.

Koala population resilience and viability

The impact of heat stress events on koala populations is not well-studied. There are no accurate data on the prevalence of heat stress in wild koala populations experiencing extended periods of high temperature. The impact of persistent drought conditions on koala populations has been shown to be significant [18, 40, 42, 43]. Heat stress often develops under drought conditions, however the impacts of prolonged drought are not the same as

the impacts of heat stress *per se*, so it is not possible to extrapolate data on drought effects and apply it to heat stress impacts on koala populations.

It is assumed that koalas will vary in their susceptibility to developing heat stress, based on physiological tolerance and on their individual environmental circumstances (availability of refugia, water sources, hydration status of available browse). The proportion of koalas experiencing heat stress, when placed in an environment of ongoing high ambient temperature, is not known. It is assumed that not all koalas at risk will develop clinical heat stress.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of heat stress to koala population resilience and viability is considered **MODERATE**.

Koala individual health and welfare

The proportion of koalas experiencing heat stress, when placed in an environment of ongoing high ambient temperature, is not known. It is assumed that not all koalas at risk will develop clinical heat stress. However, it is well-documented that individual koalas experiencing heat stress can become extremely unwell and die as a result [18, 42].

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of heat stress to koala individual health and welfare is considered **MAJOR.**

Overall risk estimate

The overall risk of heat stress to koala population resilience and viability, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **MODERATE**.

The overall risk of heat stress to individual koala health and welfare, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **HIGH.**

This assessment exceeds the acceptable risk thresholds for koala populations and individual koalas as outlined in *Appendix 2.3 Risk Assessment Methods*, therefore risk management for heat stress is recommended.

Level of confidence in risk assessment

The level of confidence in the likelihood assessment for heat stress is **MEDIUM**. Although there are excellent weather data available across the koala's natural range, there is limited information on how many koalas experiencing extremes of ambient temperature progress to clinical heat stress. The level of confidence in the consequence assessment for koala populations is **LOW** as there are no data on the prevalence of heat stress in wild koala populations experiencing extremes of ambient temperature. The level of confidence in the consequence assessment for individual koalas is **MEDIUM**. Although the severe impacts of heat stress on individual koala health and welfare have been documented, there is no data

on the proportion of koalas experiencing heat stress, when placed in an environment of ongoing high ambient temperature.

Overall, the confidence in the risk estimate for heat stress is considered **MEDIUM**.

5.3.5 Risk mitigation options

The following risk mitigation measures have been identified for heat stress. Further information and justification can be found in the *Treatment* and *Prevention and control* sections of the relevant literature review chapter. Risk mitigation options were assessed for both effectiveness and feasibility during KDRA Stakeholder Workshops, and are listed here in descending order of effectiveness and feasibility. Note: Risk mitigation options are possibilities for risk mitigation and should not be confused with recommendations for action (which are listed below).

- Identify and map koala populations likely to be susceptible to heat events, to enable spatial targeting of mitigation efforts (CCP12).
- Support the capacity of koalas to move to available water in their environment. In the wild, this includes improving water catchment and storage via artificial or natural wetlands and slowing water outflow to increase tree hydration (CCP1, CCP2, CCP13 and CCP19).
- Develop metrics for advance warning of heat stress risk (CCP19).
- Strengthen existing habitat corridors and restore habitat connectivity which has been lost, through re-vegetation and restoration projects (CCP1).
- Strengthen regulatory controls against habitat clearing and road development in koala habitat and dispersal corridors (CCP1).
- Develop and apply early intervention measures when weather forecasts or conditions indicate heat stress risk to wild koalas (e.g. provision of free water, monitoring of at-risk koala populations or individuals, with identification and removal for treatment of those with clinical heat stress) (CCP19).
- Re-vegetation, restoration and preservation of habitat, including in urban landscapes (CCP1).
- Translocate koalas shown to have higher thermal tolerance into heat-vulnerable populations, to increase genetic resilience to the threat of heat stress (CCP8).
- Select species for koala habitat revegetation that are best suited to changing climate in the bioregion and that are the most drought- and heat-tolerant (CCP1, CCP2, CCP13 and CCP19).
- Protect or develop climate refugia, such as valleys, understory, midstory and fast-growing shade-producing non-browse vegetation that provide good thermal protection for koalas (CCP1).
- For captive and rehabilitation koalas, supply free water, optimise management of cut browse to maintain leaf moisture (including regular misting), and feed koalas in the

evening rather than in the morning when weather forecasts indicate high ambient temperatures (CCP1, CCP2, CCP13 and CCP19).

- Act to bring about "climate-friendly" policies at a local, state and federal level (CCP2).
- Consider climate change projections when undertaking habitat assessment and planning for koalas (CCP2).
- Use koalas and their plight as a focus-point for community education about climate change and a "call to action" for associated behaviour change (CCP2).
- Support genetic diversity in koala populations to encourage the retention of the most robust genetic profiles for adapting to a changing climate and coping with the impacts of high ambient temperatures and drought (CCP8).
- Support soil quality and diversity, and better manage storm water run-off, to retain moisture in the soil and vegetation (CCP1, CCP2, CCP13 and CCP19).
- Translocate koalas from marginal habitat significantly compromised by climate change to more suitable locations (if available) (CCP3).
- Adopt fire management practices that minimise impacts on koala habitat quantity, quality and connectivity, to retain refugia from hot weather and minimise hydration stress on koalas and trees (see *Risk mitigation options* in *5.3 Thermal Burn Trauma* for more details) (CCP12).
- Minimise environmental stressors, concurrent infections and other causes of stress (such as general debilitation) in individual koalas, and populations, to maintain hydration, appetite and organ function and thereby reduce the risk of clinically significant consequences of exposure to high ambient temperatures (CCP14).

5.3.6 Recommendations

Recommendations for heat stress are grouped as "top priority" and "next priority" as determined through consultation during the KDRA Stakeholder Workshops.

All general recommendations listed in *Section 1.6.2* apply to heat stress.

Hazard-specific recommendations

The following recommendations are specific to this hazard:

Top priority recommendations specific to heat stress:

3.1 Identify and map koala populations likely to be susceptible to heat events to enable spatial targeting of action.

3.2 Develop community and first responder early intervention and emergency response protocols for koala populations during extreme heat events.

3.3 Develop nationally-agreed protocols for diagnosis, assessment, treatment and care of heat stressed koalas.

3.4 Conserve and improve the quality, quantity, connectivity and complexity of koala habitat and refugia, to provide good thermal protection.

3.5 Strengthen regulatory controls against clearing and development in koala habitat (including refugia).

Next priority recommendations specific to heat stress:

3.6 Support water retention and availability in koala environments.

3.7 Support fire management practices that minimise the loss of koala refugia.

3.8 Develop a nationally-applicable koala heat stress prediction tool, based on weather forecasting.

3.9 Undertake research on thermal tolerance in koalas, including whether this (or other indicators of a koala's ability to survive increased ambient temperatures) vary genetically or over the koala's range (north-south or east-west). This will help to inform the option of translocation to mitigate climate change associated risks.

5.3.7 References

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5.4 Predator Attack Trauma in Koalas – Risk Assessment

The literature review which supports this risk assessment is in *Appendix 5.4*.

5.4.1 Hazard summary

- Predator attacks are a common cause of severe and often fatal trauma to koalas.
- Domestic and wild dogs[5] are the most common cause of koala predator trauma in developed areas, and wild dogs are opportunistic predators in protected and bushland habitat [1-4].
- Non-canid predators, particularly pythons, may cause significant juvenile mortality in some koala populations [3, 5-12].
- Foxes, domestic and feral cats and raptors may also predate juvenile koalas, but the population level impacts are likely to be low.
- Koala predation may be an under-reported cause of morbidity and mortality due to the difficulties in retrieving carcasses [2, 6, 9, 10] and the challenges of recognising subtle signs of predator attack [10, 13].
- Koalas are most susceptible to predator attack during the breeding season and during dispersal, when they are more mobile and spend more time on the ground [2, 14-17]. Sick and debilitated koalas are more likely to spend time on the ground and may be at increased risk of predation [3, 7].
- The prognosis for predator trauma cases in koalas is generally poor, with mortality rates of hospital admissions as high as 69% for dog attacks [2].
- Prevention and control strategies focus on domestic dog risk mitigation [3, 18, 19], reducing wild dog impact [4, 8, 10] and ensuring habitat connectivity to minimise the amount of time koalas spend on the ground [15, 20-22].
- For further detail on current knowledge of this hazard, refer to *Appendix 5.4 Predator Attack Trauma in Koalas - Literature Review.*

5.4.2 Justification for hazard selection

Predator attacks cause significant health and welfare impacts to individual koalas [1-3, 17]. Although predation is a natural biological occurrence in wild populations, koalas are exposed to predation risks with increasing habitat loss and urbanisation because they spend more time on the ground, and are more commonly in close proximity to domestic dogs [2]. The impacts of predation can be an additional burden for koalas already debilitated by other disease [3, 7].

[5] includes dingoes, dingo-dog crosses and domestic dogs which are no longer living in a domesticated environment (as opposed to stray or unsecured pets).

5.4.3 Identified gaps in knowledge

- Robust, longitudinal data sets on causes of mortality in free-living koalas throughout their range are required to better understand predation prevalence, source of predation, and population level impacts [6].
- More consistent and effective post-release monitoring is required to determine the long-term outcomes of injured koalas, and to better evaluate the impact of predator attack on population declines [2, 4].
- Researchers, rescuers and field workers may not have the necessary knowledge to recognise predator attack signs in live and dead koalas, resulting in underreporting of this hazard [23].
- More studies are needed on the effectiveness of prevention strategies, particularly the effectiveness of community education in reducing encounters between koalas and domestic dogs [19, 24], and strategies for controlling free-ranging wild dog populations [4, 10].

5.4.4 Risk assessment

Hazard justification

Figure 8 shows a schematic of the hazard pathways and critical control points identified for this hazard. Critical control points are defined as *key* points in the hazard pathway where risk mitigation methods could be most effective (see *Appendix 2.3 Risk Assessment Methods* for further information). Nineteen CCPs (CCP1-CCP19) were identified across all hazards, but only those applicable to this hazard are described below. See *Section 6 Critical Control Points by Disease Hazard* for a summary of CCPs across all hazards selected for detailed assessment.

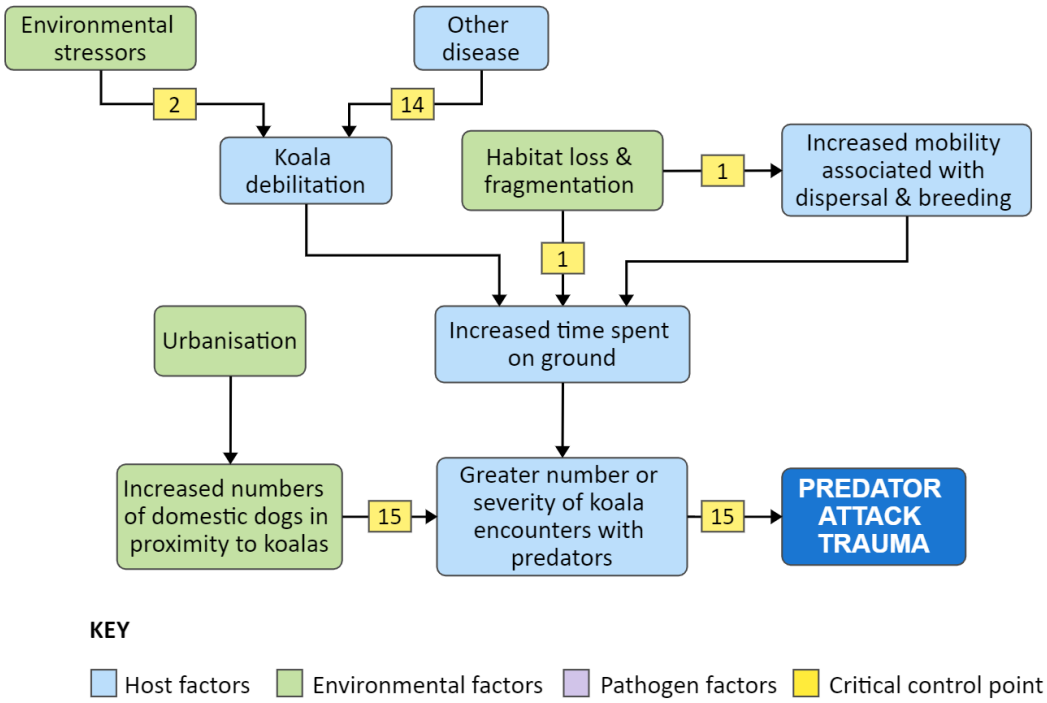

Figure 8 Hazard pathways and critical control points for predator attack trauma in koalas

Critical control points

CCP1 Habitat loss, fragmentation and reduction in quality

Habitat loss and reduction in habitat quality are major environmental stressors due to the koala's reliance on particular tree species for food, shelter and thermoregulation [25, 26]. Habitat fragmentation reduces connectivity between suitable koala habitat, increasing the amount of time koalas must spend on the ground and thereby increasing the likelihood of predator attack [2, 15, 21, 22, 27-30].

Causes include urban expansion, land clearing for production, inappropriate fire management practices, the introduction of pests, weeds and plant pathogens, over-browsing by koalas as a result of local overcrowding, and the habitat-altering effects of climate change [30-36].

CCP2 Environmental stressors

Stressors in the koala's environment (in the wild or in captivity) contribute to general debilitation of the host, reduced immune function, and increased susceptibility to disease or severity of disease expression [26, 37-39]. Major environmental stressors for koalas include habitat loss, habitat fragmentation and reduction in quality, nutritional stress, weather extremes, and disturbance related to human activities [25, 28].

Environmental stressors increase the likelihood of koala debilitation and disease, thereby increasing the likelihood of koalas going to ground, where they are more susceptible to predator attack and have reduced capacity to escape or defend themselves from predators [1, 3, 15, 40].

CCP14 Concurrent infections and debilitation

Concurrent infections and debilitation can compromise immune function and general health in ways that increase the risk or severity of disease.

In the case of predator attack, koalas debilitated from infection or other causes are more likely to be on the ground and less likely to successfully escape or defend themselves from a predator [1, 3, 15, 40].

CCP15 Exposure to predators and severity of attack

Increased numbers of domestic dogs in closer proximity to koalas increase the likelihood of koala trauma due to predation. Urbanisation increases the absolute number of pet dogs in an area, and also increases the likelihood of koalas moving through back yards where dogs are kept [18]. Attack severity depends on the size and attack style of the predator [3, 6, 13, 23, 41, 42].

Likelihood assessments

The prevalence of predation is difficult to determine, in part because of the absence of accurate population size estimates for koalas, and it is likely to be an under-recognised hazard. Available data indicates 10-29% of koala mortalities recorded by wildlife hospitals and rehabilitation facilities may be due to dog attack [2]. The likelihood of predator attack will vary based on the abundance and behaviour of predators in an area and it is likely that a significant number of cases go unreported [2, 6, 9, 10, 13].

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of a koala being attacked by a predator during its lifetime is considered **MODERATE**.

Consequence assessments

Predator trauma is a non-infectious hazard and therefore consequence assessments were not made in relation to the health and welfare of other species.

Koala population resilience and viability

Predation by both dogs and non-canid species has been demonstrated to account for 30-50% of mortalities in longitudinal studies of free-living populations in Qld and NSW [1, 10, 43]. Reported mortality rate for dog attack cases admitted to rehabilitation is over 50% and can be as high as 69% [2, 17, 44].

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of predator trauma to koala population resilience and viability is considered **MODERATE**.

Koala individual health and welfare

The reported mortality rate due to predator trauma in koala hospital and rehabilitation facility admissions is as high as 69% [17]. Severe injuries and welfare impacts are common

outcomes for koalas that survive predator attack [13, 16], and they may require prolonged treatment and rehabilitation before return to the wild.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of predator trauma to koala individual health and welfare is considered **MAJOR**.

Overall risk estimate

The overall risk of predator trauma to koala populations, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **MODERATE**.

The overall risk of predator trauma to individual koalas, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **HIGH**.

This assessment exceeds the acceptable risk thresholds as outlined in *Appendix 2.3 Risk Assessment Methods* for individual koalas and koala populations, therefore risk management for predator trauma is recommended.

Level of confidence in risk assessment

The level of confidence in the likelihood assessment is **MEDIUM** because the overall number of koalas affected by predation is difficult to determine, due to a lack of information on koala population numbers, and likely underreporting of predator trauma in wild koalas. The level of confidence in the consequence assessment for koala populations is **MEDIUM** because there are limited monitoring data for koala populations across their range. The level of confidence in the consequence assessment for individual koalas is **HIGH** as it is based on detailed documentation of hospital admissions.

Overall, the confidence in the risk estimate for predator trauma is considered **MEDIUM**.

5.4.5 Risk mitigation options

The following risk mitigation measures have been identified for predator trauma. Further information and justification can be found in the *Treatment* and *Prevention and control* sections of the relevant literature review chapter. Risk mitigation options were assessed for both effectiveness and feasibility during KDRA Stakeholder Workshops, and are listed here in descending order of effectiveness and feasibility. Note: Risk mitigation options are possibilities for risk mitigation and should not be confused with recommendations for action (which are listed below).

- Restrict domestic dog movements in koala habitat (CCP2 and CCP15).
- Provide information to dog owners on strategies to prevent backyard attacks (CCP2 and CCP15).
- Encourage responsible dog ownership, including selecting dogs of a size, breed and nature which are less likely to attack koalas and education of landowners to alter behaviours to reduce the risks to koalas of keeping domestic dogs (CCP2 and CCP15).

- Strengthen existing habitat corridors and restore habitat connectivity which has been lost, through re-vegetation and restoration projects, including revegetation in urban landscapes (CCP1).
- Employ strategies in koala habitat to reduce wild dog numbers or remove identified individual wild dogs known to specifically predate on koalas (noting the hazard-specific recommendations below, and recognising the changing understanding of the genetic provenance of "wild dogs") (CCP15).
- Apply regulations on dog size and numbers for residents near koala habitat (CCP15).
- Strengthen regulatory controls against habitat clearing and road development in koala habitat and dispersal corridors (CCP1).
- Minimise concurrent infections, debilitation and other environmental stressors (e.g. predators, disturbance related to human activities) in individual koalas and populations, as these may increase likelihood of koalas going to ground and being attacked, and may weaken the koala's ability to defend itself from attack (CCP2 and CCP14).
- Identify key dispersal corridors and prioritise habitat investment, including land purchase, incentive mechanisms for habitat preservation and provision of development and housing planning guidelines for key corridor areas (CCP1).

5.4.6 Recommendations

Recommendations for predator trauma are grouped as "top priority" and "next priority" as determined through consultation during the KDRA Stakeholder Workshops.

All general recommendations listed in *Section 1.6.2* apply to predator attack trauma.

Hazard-specific recommendations

The following recommendations are specific to this hazard:

Top priority recommendations specific to predator attack trauma:

4.1 Study the effectiveness of prevention strategies (particularly actions to reduce encounters between koalas and domestic dogs), to inform more effective mitigation strategies.

4.2 Educate dog owners on responsible and "koala-friendly" dog ownership.

4.3 Develop nationally-agreed monitoring for koalas following rehabilitation and release, to determine the long-term outcomes of koalas, and to better evaluate the impact of predator attack on population declines.

Next priority recommendations specific to predator attack trauma:

4.4 Establish restrictions on dog size, freedom-to-roam and curfews in areas adjacent to koala habitat.

4.5 Develop training resources for researchers, rescuers and field workers on recognition of signs of predator attack in live and dead koalas, to improve reliability of predator attack data.

4.6 Review strategies for controlling free-ranging wild dog populations in the context of the current understanding of the role of the dingo as an apex predator and the high level of dingo ancestry in most "wild dogs", in order to inform more effective mitigation strategies.

5.4.7 References

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5.5 Thermal Burn Trauma in Koalas – Risk Assessment

The literature review which supports this risk assessment is in *Appendix 5.5*.

5.5.1 Hazard summary

- Bushfires are an inevitable occurrence in koala habitat in Australia [1], with the extent and severity of fires predicted to increase as the effects of anthropogenic climate change are felt [2-4].
- Fire has been recognised as a contributing factor in koala population declines [4-7], and population extirpations [7-10]. However, koala populations may recover from fire events provided an adequate quality and quantity of unburnt adjacent habitat is present [11, 12].
- Burns to koalas are a common occurrence when habitat is burnt, with the risk of injury and death related to the nature and intensity of the fire (particularly the extent of forest canopy burning), the extent of koala travel over a burnt landscape, the degree of pre-existing debilitation of koalas and the interval between burn injury, rescue and treatment [1, 2, 4, 8, 13-15].
- Prompt and expert triage are essential for good welfare outcomes for burnt koalas [16, 17].
- Prevention and control strategies focused on minimising the impact of fire in the landscape will also be relevant to minimising burn risk for koalas, but risk mitigation specific for koalas is also required [1, 18].
- For further detail on current knowledge of this hazard, refer to *Appendix 5.5 Thermal Burn Trauma in Koalas - Literature Review.*

5.5.2 Justification for hazard selection

Bushfires will continue to be a feature in the Australian landscape, and burn trauma is a common and debilitating outcome for koalas when bushfires occur in their habitat.

5.5.3 Identified gaps in knowledge

- Ongoing longitudinal study is needed to fully understand the impacts of the devastating fire events of 2019-2020, and other fires, on koala populations [4, 14].
- More comprehensive data on the location and size of koala populations would assist in predicting the impact of fire on populations, targeting preventative measures and monitoring recovery [1].
- More research is needed in understanding the mortality effects and movement patterns of koalas during and after prescribed burning events, to reduce the impact of burns on koala populations [1].
- The integration of traditional Indigenous fire management knowledge with other fire management practices is an area for development in the pursuit of effective fire mitigation which also preserves ecosystem function [1, 19, 20].

- More data are needed to quantify the impact of thermal burns on the health and welfare of individual koalas [10, 13, 21, 22].
- There are currently no consistent nation-wide guidelines for the first aid, triage and clinical evaluation of burnt koalas. Consolidation of the learnings of the 2019-2020 bushfires in terms of first aid, triage, treatment and prognostic indicators for burnt koalas is needed to inform national guidelines which will improve consistency of approach and welfare-oriented outcomes for koalas.
- Robust, longitudinal data sets on causes of mortality in free-living koalas throughout their range are required to better understand the prevalence and population level impacts of thermal burn trauma.

5.5.4 Risk assessment

Figure 9 shows a schematic of the hazard pathways and critical control points identified for this hazard. Critical control points are defined as *key* points in the hazard pathway where risk mitigation methods could be most effective (see *Appendix 2.3 Risk Assessment Methods* for further information). Nineteen CCPs (CCP1-CCP19) were identified across all hazards, but only those applicable to this hazard are described below. See *Section 6 Critical Control Points by Disease Hazard* for a summary of CCPs across all hazards selected for detailed assessment.

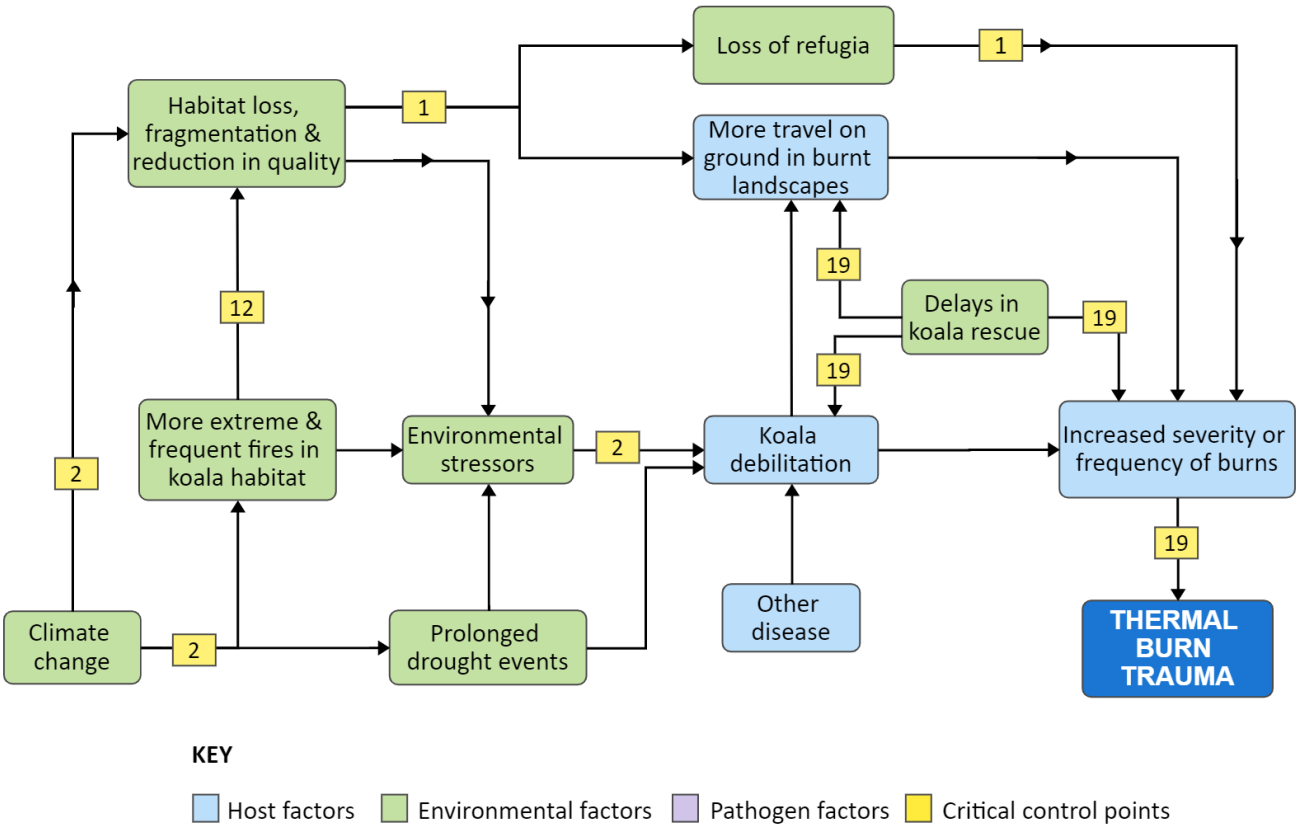

Figure 9 Hazard pathways and critical control points for thermal burn trauma in koalas

Critical control points

CCP1 Habitat loss, fragmentation and reduction in quality

Habitat loss and reduction in habitat quality are major environmental stressors due to the koala's reliance on particular tree species for food, shelter and thermoregulation [23, 24]. Habitat fragmentation reduces connectivity between suitable koala habitats, forcing dispersal and potentially contributing to the loss of important genetic alleles in populations that can no longer interbreed [25-27]. Causes include urban expansion, land clearing for production, inappropriate fire management practices, the introduction of pests, weeds and plant pathogens, over-browsing by koalas as a result of local overcrowding, and the habitat-altering effects of climate change [20, 28-33].

Habitat loss, reduction and fragmentation all result in loss of refugia, increasing likelihood of burns in the event of a fire as koalas are unable to find shelter or food, and are more likely to travel over burnt ground in search of suitable habitat [11, 12, 34, 35].

CCP2 Environmental stressors

Stressors in the koala's environment (in the wild or in captivity) contribute to general debilitation of the host, reduced immune function, and increased susceptibility to disease or severity of disease expression [24, 36-38]. Major environmental stressors for koalas include habitat loss, fragmentation and reduction in quality; nutritional stress; climate change; extremes of weather and disturbance related to human activities [23, 39].

Climate change is a key environmental stressor which leads to more extreme and frequent fires in koala habitat, resulting in greater likelihood of burn trauma [1, 8]. Many significant bushfires are preceded by prolonged drought and heat events [14, 28, 40-42].

CCP12 Fire management practices

Inadequate planning, inappropriate methodology or flawed execution of fire management practices may lead to increased disease risks for koalas [1, 19].

The risk of burns to koalas is related to the nature and intensity of the fire (particularly the extent of forest canopy burning) and the extent of koala travel over a burnt landscape [1, 13, 15]. The extent to which planning and execution of fire management incorporates koala risk mitigation will affect the likelihood and consequences of burns to koalas.

CCP19 Emergency response to heightened risk

In situations where environmental conditions are associated with increased disease threats (e.g. bushfires, high ambient temperatures), *in situ* preparedness and response activities may significantly reduce risk to koalas. Actions may include community awareness and behaviour change campaigns (e.g. [43, 44]) as well as advance planning for emergencies, and deployment of rapid response teams (e.g. [13, 15]).

In the case of burns, actions include fire warning protocols to enable consideration of koala rescue before fires reach populations, early deployment of koala rescue teams into burnt

areas and establishment of best practice protocols for first aid, triage and treatment of burnt koalas [1, 13, 15, 45].

Likelihood assessments

It appears certain that there will be increasing severity and frequency of bushfire events in koala habitat, as a result of climate change [1, 8]. The ability of koalas to escape the effects of fire is affected by a range of factors, including the nature of the burn [1, 4, 8], the availability of adjacent unburnt habitat [1, 11, 12], and the availability of timely, expert treatment [13, 15].

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of a koala being burnt in a bushfire during its lifetime is considered **MODERATE**.

Consequence assessments

Thermal burn trauma is a non-infectious hazard and therefore consequence assessments were not made in relation to the health and welfare of other species.

Koala population resilience and viability

The potentially devastating consequence of koala burns to population viability was highlighted during the 2019-20 fires, when an estimated 60,000 koalas perished and over 10% of total wild koala habitat was burned [8, 46]. Despite these estimates, more data is required on the impacts of fire on free-living koala populations, in both the short and long term. The effects of climate change are likely to increase bushfire severity [1, 8] and the small size and high fragmentation of current koala populations will increase the likelihood of population declines and extirpation as a result of fire [4]. However, koala populations have been shown to recover from fire events under certain conditions [11, 12].

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of thermal burns to koala population resilience and viability is considered **MODERATE**.

Koala individual health and welfare

Koalas that are burnt often suffer injuries which are fatal or require euthanasia [13, 22]. Poor body condition, dehydration and the effects of smoke inhalation commonly occur along with burn trauma and reduce the koala's chances for recovery [13]. Koalas that survive thermal burns may require extended periods of care and treatment [15]. Burn recovery is known to be a painful process in humans [47], and the same may be true for koalas.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of thermal burn trauma to koala individual health and welfare is considered **MAJOR**.

Overall risk estimate

The overall risk of thermal burn trauma to koala population resilience and viability, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **MODERATE**.

The overall risk of thermal burn trauma to individual koalas, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods* is **HIGH**.

This assessment exceeds the acceptable risk thresholds as outlined in *Appendix 2.3 Risk Assessment Methods* for both koala populations and individuals, therefore risk management for thermal burn trauma in koalas is recommended.

Level of confidence in risk assessment

There is considerable data on the likely impacts of climate change on bushfire events in the Australian context. Data on the absolute numbers of koalas which experience burn trauma is often incomplete because of logistic and safety constraints to timely access to fire grounds to enable koala rescue [13]. Uncertainties regarding free-ranging koala population numbers also limit full evaluation of the impact of fires [1]. The level of confidence in the assessment of likelihood for this hazard is therefore assessed as **MEDIUM.**

There are knowledge gaps in our understanding of the resilience of koala populations to fire [1]. Separation of the impact of thermal burns *per se* from other effects of fire such as habitat loss and nutritional stress is rarely attempted [13]. Therefore, the level of confidence in the assessment of consequence of thermal burns on koala population resilience and viability is **MEDIUM**. The level of confidence in the assessment of consequence for individual koalas is **HIGH** as the clinical and welfare impacts of burns in koalas are well documented.

Overall, the confidence in the risk estimate for burns trauma is **MEDIUM**.

5.5.5 Risk mitigation options

The following risk mitigation measures have been identified for thermal burn trauma. Some of these focus on mitigating the impacts of bushfires in general and others focus on mitigating the impacts of burn trauma on individual koalas. Further information and justification can be found in the *Treatment* and *Prevention and control* sections of the relevant literature review chapter. Risk mitigation options were assessed for both effectiveness and feasibility during KDRA Stakeholder Workshops, and are listed here in descending order of effectiveness and feasibility. Note: Risk mitigation options are possibilities for risk mitigation and should not be confused with recommendations for action (which are listed below).

- Develop decision trees and protocols to improve the consistency and effectiveness of koala triage for positive koala welfare and successful treatment outcomes (CCP12 and CCP19).

- Support the training of rehabilitators and veterinary personnel in incident management and moving within burnt landscapes to improve the safe and timely integration of animal rescue into bushfire response (CCP12 and CCP19).
- Support early intervention and enable timely access to firegrounds by personnel experienced and trained in koala rescue, triage and treatment (CCP12 and CCP19).
- Incorporate koala response and rescue into fire emergency response planning at all jurisdictional levels (CCP12).
- Protect or develop climate refugia, such as valleys, understory, midstory and fast-growing shade-producing non-browse vegetation that provide good thermal protection for koalas (CCP1).
- Use of technologies to locate free-living koalas, then protect or evacuate them prior to, or during, fires (CCP12).
- Re-vegetation, restoration and preservation of habitat, including in urban landscapes, to restore habitat connectivity and strengthen existing habitat corridors (CCP1).
- Support personal mental health and welfare care plans, based on science and experience, for all personnel involved in rescue, treatment and care of injured wildlife (CCP12 and CCP19).
- Schedule burning to avoid koala breeding and dispersal periods (CCP12).
- Strengthen regulatory controls against habitat clearing and road development in koala habitat and dispersal corridors (CCP1).
- Identify and map koala populations to facilitate location and response in the event of a fire (CCP12).
- Reduce fuel load around tree bases and wet trunks of trees known to be used by koalas (CCP12).
- Improve fire resilience of habitat by selecting rapid-growing shelter trees and heat-tolerant species (CCP1).
- Act to bring about “climate-friendly” policies at a local, state and federal level (CCP2).
- Use koalas and their plight as a focus-point for community education about climate change and a “call to action” for associated behaviour change (CCP2).
- Adopt fire management practices that minimise impacts on koala habitat quantity, quality and connectivity (CCP12).
- Promote practices which reduce the impacts of climate change (CCP2).

5.5.6 Recommendations

Recommendations for thermal burn trauma are grouped as “top priority” and “next priority” as determined through consultation during the KDRA Stakeholder Workshops.

All general recommendations listed in *Section 1.6.2* apply to thermal burn trauma.

Hazard-specific recommendations

The following recommendations are specific to this hazard:

Top priority recommendations specific to thermal burn trauma:

5.1 Develop nationally-agreed protocols and decision trees for triage, assessment, treatment and rehabilitation of burnt or fire-affected koalas, including criteria for euthanasia.

5.2 Incorporate protocols for early first responder intervention and response for koalas into fire emergency response planning.

5.3 Continue long-term longitudinal studies to fully understand the impacts of the 2019-2020 (and other) fire events on koala populations.

5.4 Train wildlife rehabilitators and veterinary personnel during "peacetime" in incident management and safe access to fire fields to allow timely integration of animal rescue into bushfire response.

5.5 Develop nationally-agreed monitoring protocols for koalas following rehabilitation and release, to evaluate the short- and long-term impacts of thermal trauma on individuals and populations and to inform further refinement of rescue and rehabilitation practices.

Next priority recommendations specific to thermal burn trauma:

5.6 Integrate traditional and Indigenous fire management knowledge into current fire management practices.

5.7 Study movement patterns of koalas during and after prescribed burning events.

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5.6 *Cryptococcus* spp. in Koalas – Risk Assessment

The literature review which supports this risk assessment is in *Appendix 5.6*.

5.6.1 Hazard summary

- The fungal organism *Cryptococcus gattii* is the major cause of cryptococcal infection in koalas [1], probably because of its strong association with tree species commonly used by koalas for food and shelter [2-4].
- *Cryptococcus gattii* is widely distributed throughout Australia and koala habitats, with different molecular types predominating in different regions [5].
- Although the various molecular types of *C. gattii* are commonly associated with eucalypts and other native Australian trees, the tree species is likely to be less important than the capacity of the tree to form decayed hollows as an effective substrate for the organism [6-8].
- Koalas acquire *C. gattii* by inhaling the organisms from the environment [9]. Nasal colonisation with *C. gattii* occurs commonly in healthy koalas subsequent to exposure, and in most cases will either resolve spontaneously, or persist indefinitely without progressing to disease [10].
- In some koalas, nasal colonisation may progress to subclinical infection [9, 11]. In subclinical infection, early, limited invasion of the respiratory system occurs without clinical signs or identifiable lesions but with cryptococcal antigen detectable in the host blood (known as antigenaemia). Subclinical infection may resolve or progress to cryptococcal disease [9, 11, 12].
- Cryptococcal disease is much less prevalent than nasal colonisation or subclinical infection. It is not an inevitable sequel of these earlier phases of infection [7, 9, 11, 12], suggesting that in most cases of nasal colonisation or subclinical infection, the host immune response is sufficient to contain or eliminate the pathogen [13].
- Cryptococcal disease (cryptococcosis) in koalas has been most studied in NSW, and there is a strong regional bias to NSW in reported cases [11, 12, 14]. Cryptococcosis also occurs in captive and wild koalas in Qld and sporadically elsewhere in captive koalas [15-17]. There are no reports of cryptococcosis in free-ranging koalas in SA or Vic.
- Cryptococcal disease is likely to be precipitated by stress, including poor nutrition, starvation, illness due to other causes, and transport [5, 10, 18].
- Cryptococcal disease most often occurs in captivity, but outbreaks in free-ranging animals occur [14, 15]. It is thought that koalas can amplify *Cryptococcus* in their immediate environment [11, 18], which could be a factor in the higher incidence of disease in captivity.
- Signs of cryptococcal disease are commonly respiratory (sneezing, nasal discharge, nose bleed, facial distortion, pneumonia), but the organism may spread to other

organs, particularly the nervous system, with associated clinical signs. Affected koalas are generally unwell and have depression, inappetence and weight loss [10, 14, 19].

- Treatment of cryptococcal disease is very challenging and is generally only attempted in captive koalas [10, 20-23]. Serological screening tools are highly effective in detecting antigenaemia in the subclinical stages when disease management is more likely to succeed [10].
- For further detail on current knowledge of this hazard, refer to *Appendix 5.6 Cryptococcus spp.in Koalas - Literature Review.*

5.6.2 Justification for hazard selection

Cryptococcal disease is a significant cause of morbidity and mortality in some captive colonies of koalas [17]. It can also cause morbidity and mortality in wild koalas [14].

5.6.3 Identified gaps in knowledge

- Comprehensive environmental surveillance for *C. gattii* is needed to understand its geographic range and environmental niche and to clarify how molecular type and genotype influence environmental colonisation [6].
- Information on the prevalence of both *C. gattii* and cryptococcal disease in koala populations outside of NSW (both wild and captive) is needed to better understand the significance of this hazard in koalas.
- Understanding of the mechanisms through which koalas amplify *Cryptococcus* load in the environment is needed to mitigate the risk of environmental build-up of *Cryptococcus* in captive koala colonies.
- Understanding of the role of koala immune function in preventing the progression of nasal colonisation to cryptococcal disease is needed.
- Investigation of the role of co-infections such as KoRV in the progression to cryptococcal disease in koalas is required.
- The risks posed by introducing novel cryptococcal molecular types to a koala population, particularly for captive koalas, require further investigation.
- Knowledge of the pharmacokinetics of suitable drugs in koalas is needed to improve treatment options for diseased koalas.

5.6.4 Risk assessment

The great majority of cases of *Cryptococcus* infection in koalas are caused by *C. gattii* [1]. For this reason, this risk assessment considered only *C. gattii*. However, risk mitigation options are also likely to be valid for other *Cryptococcus* species.

Figure 10 shows a schematic of the hazard pathways and critical control points (CCPs) identified for this hazard. Critical control points are *key* points in the hazard pathway where risk mitigation methods could be most effective (see *Appendix 2.3 Risk Assessment Methods* for further information). Nineteen CCPs (CCP1-CCP19) were identified across all hazards, but only those applicable to this hazard are described below. See *Section 6 Critical Control*

Points by Disease Hazard for a summary of CCPs across all hazards selected for detailed assessment.

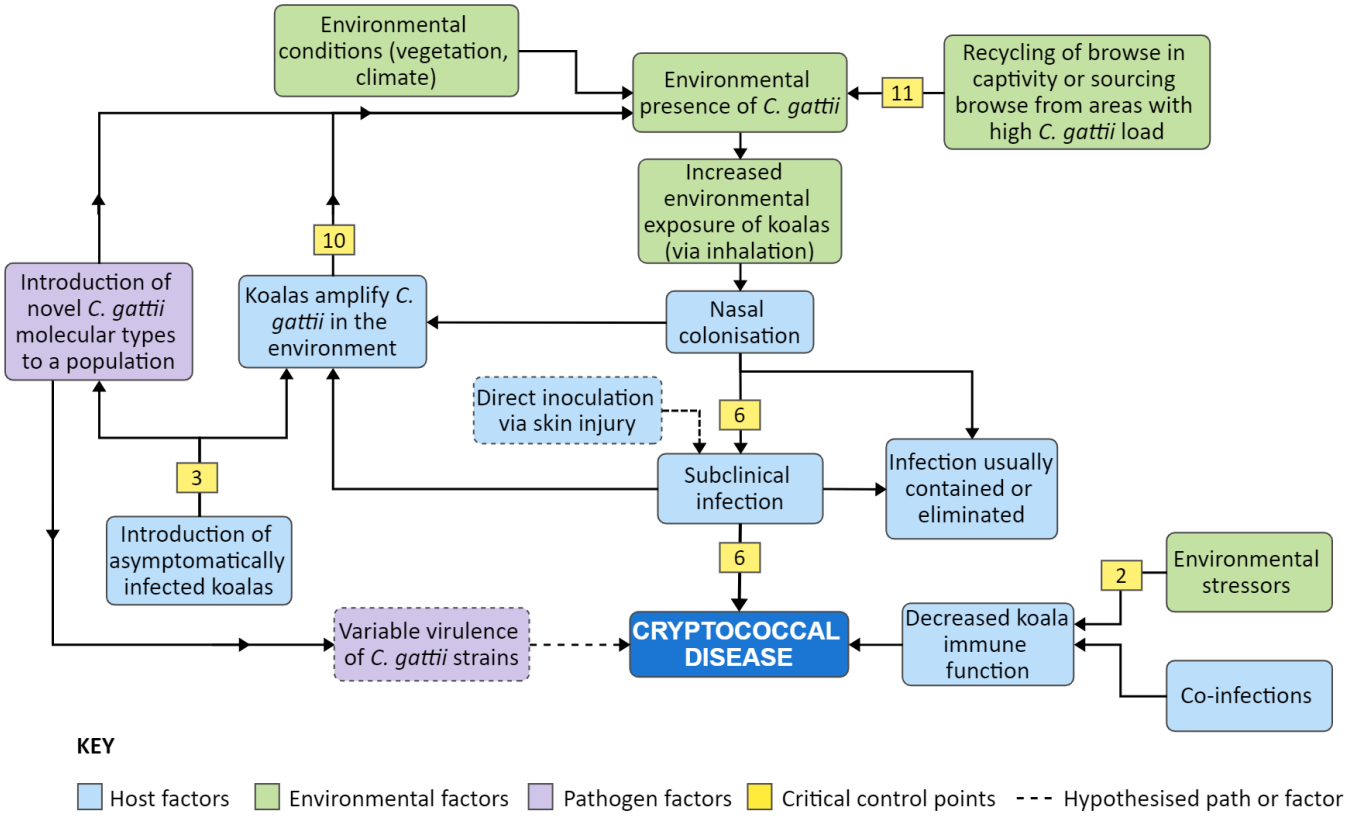

Figure 10 Hazard pathways and critical control points for cryptococcal disease in koalas

Critical control points

CCP2 Environmental stressors

Stressors in the koala's environment (in the wild or in captivity) contribute to general debilitation of the host, reduced immune function, and increased susceptibility to disease or severity of disease expression [24-27]. Major environmental stressors for koalas include habitat loss, fragmentation and reduction in quality; nutritional stress; climate change; extremes of weather and disturbance related to human activities [28, 29].

In particular, environmental stressors may play a role in the progression from nasal colonisation to subclinical infection to cryptococcal disease in koalas [10, 12, 18]. Transport stress is an important consideration for the development of cryptococcal disease in captive koalas [5].

CCP3 Koala relocation

Human-mediated movement of koalas may increase disease risk by introducing pathogens, or new pathogen varieties [30]. In the case of *Cryptococcus,* this is most likely to be significant when captive koalas are transferred between regions where the molecular types of *C. gattii* endemic in the environment are different (e.g. [5]).

CCP6 Diagnostics

Detection of nasal colonisation and subclinical cryptococcal infection cases through diagnostic testing may allow early management or treatment and halt progression to cryptococcal disease [10].

CCP10 Pathogen amplification

Cryptococcal load in the immediate environment may be increased due to the amplification of *C. gattii* by infected koalas [11, 18]. This is primarily a consideration for captive koalas or koalas in rehabilitation.

CCP11 Increased pathogen load

An increase in the load of an infectious pathogen that a koala is exposed to, or that a koala carries, influences the severity of disease caused by that pathogen.

Contaminated browse may increase the environmental load of *C. gattii* for koalas in the captive environment [10].

Likelihood assessments

The likelihood of entry and exposure of koalas was considered for "environment to koala population", "koala population to koala population" and "other animal population to koala population" transmission pathways. Likelihood of an infected koala causing a hazard to humans or other animals (via their exposure to koalas or koala environments) was also evaluated.

Entry assessment - koalas

Cryptococcus organisms are widespread throughout the environment in Australia [31]. *Cryptococcus gattii* is present in tropical, subtropical and temperate regions worldwide and has been detected throughout the free-ranging and captive distribution of the koala in Australia [5, 10]. *Cryptococcus gattii* VGI, the cause of most cases of cryptococcal disease in koalas, has a strong association with *Eucalyptus* spp., the main food trees of koalas [2]. Heavy environmental loads of *C. gattii* may occur in the wild in the absence of koalas [11]. In captive environments, high koala density may be important to maintaining a high environmental presence of *C. gattii* [32], and koalas may amplify *C. gattii* in their immediate environment [11, 18].

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of *C. gattii* entering, or being present, in a koala population is considered **HIGH**.

Exposure assessment - koalas

The likelihood of exposure to *C. gattii* refers to the likelihood that an individual koala will be exposed to *C. gattii,* regardless of whether the individual becomes infected.

Exposure of koalas to *C. gattii* occurs via inhalation of environmental cryptococcal organisms [9, 10], which accumulate in tree hollows [33]. *Cryptococcus gattii* molecular types are present in all environments where Australian koalas live [5, 10].

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of exposure to *C. gattii* for an individual koala is considered **HIGH**.

Using the principles of combining entry and exposure likelihood as outlined in *Appendix 2.3 Risk Assessment Methods*, the combined likelihood of entry and exposure for *C. gattii* in koalas is considered **HIGH**.

Likelihood assessments for other species exposed to koalas

Cryptococcus gattii is acquired from the environment rather than via transmission between hosts. There are no reported cases where amplification of the cryptococcal environmental load by koalas (either in the wild or in captivity) was thought to have led to *C. gattii* infection in humans.

In captivity, the amplification of *Cryptococcus* by koalas may increase the cryptococcal load on browse and in the environment. This has been associated with the development of *C. gattii* disease in other species in the same facility when koala browse was re-used as substrate for other species [10].

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of exposure to *C. gattii* for humans due to koalas is considered **NEGLIGIBLE**. Therefore, as outlined in *Appendix 2.3 Risk Assessment Methods,* the risk estimate for humans is classified as **NEGLIGIBLE** and the risk analysis for humans is concluded at this point.

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of exposure to *C. gattii* for other animal species due to koalas is considered to be **NEGLIGIBLE** in wild populations and **LOW** in captive and rehabilitation facilities**.** Therefore, as outlined in *Appendix 2.3 Risk Assessment Methods,* the risk estimate for wild populations of other species is classified as **NEGLIGIBLE** and the risk analysis for wild populations of other species is concluded at this point. Risk analysis for other species in captive and rehabilitation facilities continues below.

Consequence assessments

Not all exposure to *C. gattii* will result in infection of koalas. If infection of koalas does occur, this can progress in consequence from nasal colonisation (which is common and generally self-resolving) to subclinical infection (early, limited respiratory infection with antigenaemia) and ultimately to clinical cryptococcal disease [9, 11]. The low reported prevalence of cryptococcal disease, given the ubiquity of *Cryptococcus* in the environment, suggests that in the majority of cases of infection, the koala's immune response is sufficient to contain or eliminate the pathogen [13], and disease does not ensue.

Most cases of nasal colonisation in both captive and free-ranging koalas do not progress to disease, although disease is more common in the captive setting [8, 11, 14, 18, 34]. In retrospective post mortem studies, only 3–4% of koalas (mostly from NSW) had cryptococcal lesions [18]. There are no reports of cryptococcal disease in free-ranging koalas in SA and Vic [35].

Koala population resilience and viability

There is little information on the prevalence of cryptococcal colonisation, infection and disease in free-ranging koala populations outside of NSW. In one NSW free-ranging population, the prevalence of nasal colonisation was 6%, and the prevalence of antigenaemia due to subclinical infection was 7% [18]. While clusters of cryptococcal disease have been reported in free-ranging koala populations [14, 18], there is no suggestion that these resulted in a population decline. The majority of nasal colonisation and subclinical infection cases will not progress to cryptococcal disease in either the free-ranging or captive environment. It therefore will not have an impact on koala population health and viability.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of *C. gattii* infection to koala population resilience and viability is considered **MINOR**.

Koala individual health and welfare

Most koalas infected with *C. gattii* will resolve the infection at the nasal colonisation or subclinical infection stage without progressing to clinical disease [8, 11, 14, 18, 34]. The progression to clinical disease is a more common consequence in the captive environment. However, it is still much less prevalent than infection without disease, given nasal colonisation may have close to 100% prevalence and subclinical infection >50% prevalence in captive facilities [11, 12, 23]. This evaluation of the consequence of *C. gattii* disease for individual koalas incorporated the low rates at which exposure has been shown to progress to disease and the significant consequences for individual health and welfare for the small proportion of animals in which severe disease occurs.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of *C. gattii* infection to koala individual health and welfare is considered **MINOR** in the free-ranging environment and **MODERATE** in the captive and rehabilitation setting.

Health and welfare of other species

Evaluation of the overall consequences of *C. gattii* disease in koalas for individuals of other species incorporated the low reported rates at which exposure to koalas (or their environments) has been shown to lead to disease, as well as the consequences for individual health and welfare for the small proportion in which severe disease occurs.

Most other animal species exposed to *C. gattii* will not develop disease. However, when it occurs, cryptococcal disease can have severe and fatal consequences in many species of Australian wildlife [1, 10, 36-41]. Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of exposure to *C. gattii* for the health and welfare of other species is considered **MINOR**.

Overall risk estimate

The overall risk of *C. gattii* infection to koala populations, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **MODERATE**.

The overall risk of *C. gattii* infection to individual koalas, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **MODERATE** in free-ranging koalas and **HIGH** for koalas in captivity or rehabilitation.

The overall risk of *C. gattii* infection to the health and welfare of other species, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods* is **LOW** for animals in captivity where koalas are present**.**

This assessment exceeds the acceptable risk thresholds outlined in *Appendix 2.3 Risk Assessment Methods* for koala populations, individual koala health and welfare, and health and welfare of other species in captivity. Therefore, risk management for *C. gattii* is recommended for these groups.

Level of confidence in risk assessment

Factors associated with *C. gattii* in the koala environment are well recognised and well-studied. Therefore, the level of confidence in the likelihood assessment is **HIGH**.

Cryptococcal disease is not well studied outside of NSW in free-ranging populations. There is little information on the proportion of koalas exposed to *C. gattii* that progress to infection and disease. The level of confidence in the consequence assessments for populations is **LOW**.

The clinical effects of *C. gattii* infection on the health and welfare of koala individuals are well documented. The proportion of koalas that develop serious disease consequences due to exposure is not well understood, and the consequences for humans and other species of exposure to koalas are not well studied. The level of confidence in the consequence assessments for individual koalas is **MODERATE**.

The effects of *C. gattii* on the health and welfare of other species are well documented. However, the role of koalas in amplifying *C. gattii* in their immediate environment, and the importance of this amplification in increasing the risk to other animals sharing their environment, is not well understood. The confidence level in the consequence assessments for humans and other species is **MODERATE**.

Overall, the confidence in the risk estimate for *C. gattii* is considered **MODERATE**.

5.6.5 Risk mitigation options

The following risk mitigation measures have been identified for *Cryptococcus* spp. Further information and justification can be found in the *Treatment* and *Prevention and control* sections of the relevant literature review chapter. Risk mitigation options were assessed for both effectiveness and feasibility during KDRA Stakeholder Workshops, and are listed here in descending order of effectiveness and feasibility. Note: Risk mitigation options are possibilities for risk mitigation and should not be confused with recommendations for action (which are listed below).

- Avoid re-use of koala browse for other captive animals (CCP10 and CCP11).
- Avoid transport of koalas where nasal colonisation or antigenaemia has been identified (CCP3).
- Regular decontamination of captive environment to reduce cryptococcal load (CCP10 and CCP11).
- Early management of captive koalas with nasal colonisation or subclinical infection to prevent progression to cryptococcal disease (CCP6).
- Regular testing of captive koalas for cryptococcal colonisation and subclinical infection, and early treatment if needed (CCP6).
- Test wild koalas for *Cryptococcus* when they come into care, and manage positive cases appropriately (CCP6).
- Minimise stress in koalas being translocated or relocated (CCP3).
- Avoid collecting browse from locations where cryptococcal disease outbreaks have been reported in free-ranging koalas (CCP11).
- Minimise stresses to reduce the risk of disease developing in koalas with *Cryptococcus*, particularly where nasal colonisation or antigenaemia has been identified (CCP2).

5.6.6 Recommendations

Recommendations for *Cryptococcus* are grouped as “top priority” and “next priority” as determined through consultation during the KDRA Stakeholder Workshops.

All general recommendations listed in *Section 1.6.2* apply to *Cryptococcus.*

Hazard-specific recommendations

The following recommendations are specific to this hazard:

Top priority recommendations specific to Cryptococcus:

6.1 Develop nationally-agreed guidelines for the diagnosis, prevention and treatment of cryptococcal disease in koalas.

6.2 Develop national protocols for recording and communicating diagnosis of cryptococcal disease in wild and rehabilitation koalas, and map 'hot spots' of disease prevalence in the wild.

Next priority recommendations specific to Cryptococcus:

6.3 Review current protocols on sampling, storage and testing of samples for *Cryptococcus* spp. infection, with a view to creating nationally-agreed protocols

5.6.7 References

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5.7 Motor Vehicle Trauma in Koalas – Risk Assessment

The literature review which supports this risk assessment is in *Appendix 5.7*.

5.7.1 Hazard summary

- Motor vehicle accidents (MVA) cause severe and often fatal trauma to koalas [1, 2].
- Urbanisation and habitat fragmentation increase the likelihood of koalas encountering roads, which in turn increases the risk of motor vehicle trauma [3, 4].
- Male koalas during breeding season, and dispersing young, are more likely to cross roads, and are overrepresented in MVA trauma admissions and fatality records [5].
- The prognosis for motor vehicle trauma is generally poor, with high fatality and euthanasia rates reported in koalas [6, 7].
- Motor vehicle trauma tends to affect otherwise healthy koalas [6, 8], and is likely to result in the loss of the most viable individuals in a population.
- The effectiveness of prevention and control strategies for koala MVA requires more study. Effective reduction of motor vehicle trauma will likely involve a combination of habitat restoration [9-12] and specific MVA mitigation methods [10, 13-19].
- For further detail on this hazard, refer to *Appendix 5.7 Motor Vehicle Trauma in Koalas - Literature Review.*

5.7.2 Justification for hazard selection

Motor vehicle trauma is the most common cause of trauma-related koala admissions to rehabilitation facilities. In many cases it is also the most common cause of death among koalas entering rehabilitation [3, 6, 8, 20, 21]. With ongoing habitat loss and land development, koalas are increasingly exposed to roads and motor vehicles [11]. For dispersing juveniles and breeding males which travel significant distances as a normal activity, encounters with roads are likely. Normal activity patterns mean koalas are most likely to be active during the times of peak traffic and diminished visibility, increasing the risks of MVA.

5.7.3 Identified gaps in knowledge and information needs

- The effectiveness of prevention and control strategies for koala MVA is insufficiently studied and poorly understood. Given the potentially high economic cost of mitigation strategies such as traffic modification, physical barriers and road-crossing structures [10, 11], this knowledge is critical to appropriate risk management.
- Better understanding of koala movement patterns is needed. Longitudinal tracking studies would assist in informing development plans, habitat preservation and rehabilitation efforts [12].
- The identification of “black spots” for koala MVA across their range would assist in targeting mitigation practices [14, 22, 23].

- Robust, longitudinal data sets on causes of mortality in free-living koalas throughout their range are required to better understand the prevalence, source, and population level impacts of motor vehicle trauma.
- More consistent and effective post-release monitoring is needed as it would assist in determining the success of treatment of injured koalas, as well as more clearly evaluating the impact of motor vehicle trauma on populations.

5.7.4 Risk assessment

Figure 11 shows a schematic of the hazard pathways and critical control points identified for this hazard. Critical control points are defined as *key* points in the hazard pathway where risk mitigation methods could be most effective (see *Appendix 2.3 Risk Assessment Methods* for further information). Nineteen CCPs (CCP1-CCP19) were identified across all hazards, but only those applicable to this hazard are described below. See *Section 6 Critical Control Points by Disease Hazard* for a summary of CCPs across all hazards selected for detailed assessment.

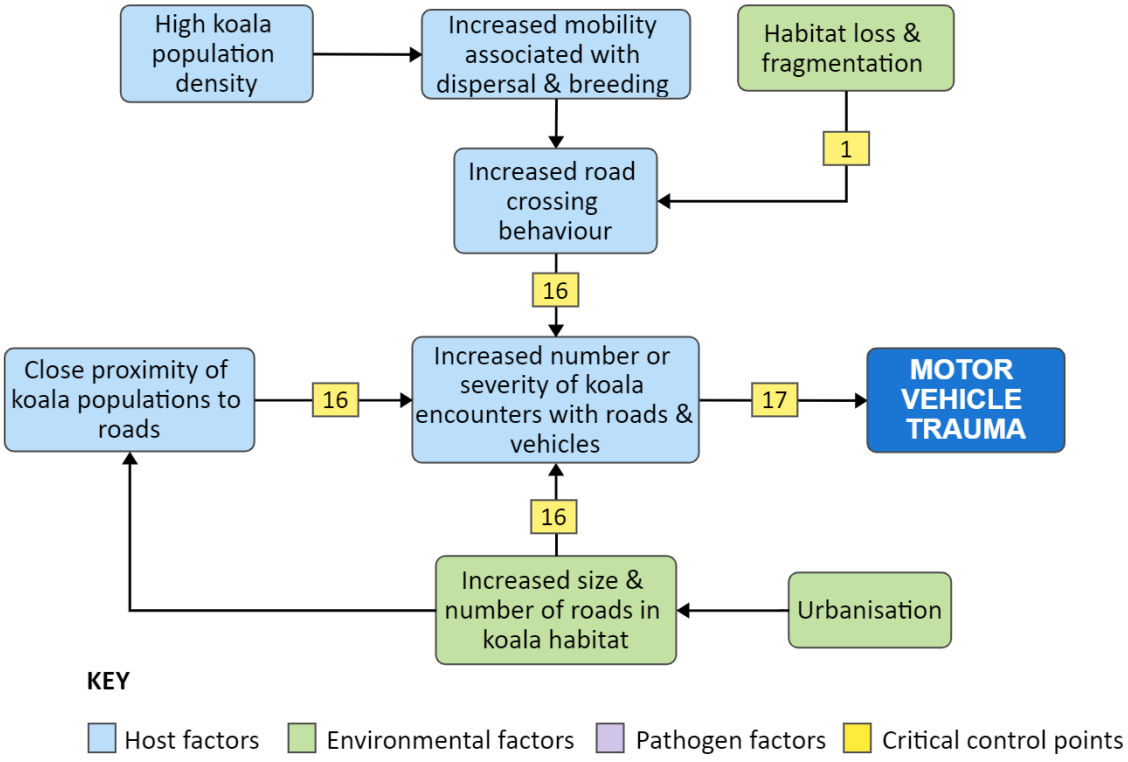

Figure 11 Hazard pathways and critical control points for motor vehicle trauma in koalas

Critical control points

CCP1 Habitat loss, fragmentation and reduction in quality

Habitat loss and reduction in habitat quality are major environmental stressors due to the koala's reliance on particular tree species for food, shelter and thermoregulation [24, 25]. Habitat fragmentation reduces connectivity between suitable koala habitat, forcing

dispersal and causing koalas to spend more time on the ground, moving between trees and increasing the likelihood of encountering roads and vehicles [3, 9, 13, 22]. Poor quality habitat may force koalas to move greater distances in search of food and shelter, increasing the likelihood of crossing more roads during their travels [12].

Causes of habitat loss and fragmentation include urban expansion, land clearing for production, inappropriate fire management practices, introduction of pests, weeds and plant pathogens, and the habitat-altering effects of climate change [4, 26-30]. In areas of localised overcrowding of koalas in remaining habitat, over-browsing by koalas can be a contributing factor [31].

CCP16 Exposure to roads

Land clearing as a result of urbanisation increases the likelihood that koalas will encounter roads within their habitat [3, 9, 13, 22]. Larger roads and more roads in a koala's habitat increase the likelihood of MVA and associated trauma [32]. Koalas that cross roads more frequently, or that have unimpeded access to roads, will be at higher risk of motor vehicle trauma [5, 16].

CCP17 Severity of trauma from vehicle impact

Higher vehicle speeds may increase the severity of trauma or the likelihood of fatality to koalas involved in MVA [14]. Koalas usually cross roads at night, when there may be low visibility and reduced avoidance behaviour due to driver fatigue [32, 33].

Likelihood assessments

A koala's need to travel on the ground will frequently bring it into contact with roads. Koalas are generally slow moving and are most likely to cross roads at twilight or in darkness when driver visibility is poor [32, 33].

Motor vehicle accidents account for a variable percentage of koala hospital admissions in Australia (see Table 18 in *Appendix 5.5 Motor Vehicle Trauma - Literature Review*), although these figures probably underestimate the overall impact of motor vehicle trauma, as data on fatalities which are not admitted to care are not captured [34]. It is not possible at this time to estimate the proportion of the free-ranging koala population that is affected by motor vehicle trauma. The likelihood of MVA will vary significantly across koala populations and between individuals. Populations situated near busy roads will be at increased likelihood of MVA.

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of an individual free-ranging koala experiencing MVA during the course of its lifespan is considered **LOW** (however, see level of confidence in this assessment below).

Consequence assessments

Motor vehicle trauma is a non-infectious hazard and therefore consequence assessments were not made in relation to the health and welfare of other species.

Koala population resilience and viability

Because habitat fragmentation leads to small islands of koala populations, often hemmed in by roads, motor vehicle trauma may cause sufficient mortality to contribute to koala population decline. This may make small populations vulnerable to local extirpation [35]. In addition, MVA trauma more commonly affects healthy animals, eliminating otherwise viable animals from populations [6, 8]. Deaths from koala MVA may result in small to moderate population level declines in vulnerable areas.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of motor vehicle trauma to koala population resilience and viability is considered **MODERATE**.

Koala individual health and welfare

Koala MVAs have a high fatality rate and a high rate of euthanasia [3, 7, 12, 21, 22, 36].

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of vehicle trauma to koala individual health and welfare is considered **MAJOR**.

Overall risk estimate

The overall risk of motor vehicle trauma to koala populations, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods* is **LOW**.

The overall risk of motor vehicle trauma to individual koalas, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods* is **MODERATE**.

This assessment exceeds the acceptable risk thresholds as outlined in *Appendix 2.3 Risk Assessment Methods*, therefore risk management for motor vehicle trauma is recommended.

Level of confidence in risk assessment

The confidence in the likelihood assessment is **MEDIUM** because estimates of free-ranging koala populations are uncertain, and the overall number of koalas affected by motor vehicle trauma cannot be extrapolated from hospital admissions data. The confidence in the consequence assessment for populations is **MEDIUM** for the same reason. The confidence in the consequence assessment for individual koalas is **HIGH** as it is based on detailed documentation of hospital admissions.

Overall, the confidence in the risk estimate for motor vehicle trauma is considered **MEDIUM**.

5.7.5 Risk mitigation options

The following risk mitigation options have been identified for motor vehicle trauma. Further information and justification can be found in the *Treatment* and *Prevention and control* sections of the relevant literature review chapter. Risk mitigation options were assessed for both effectiveness and feasibility during KDRA Stakeholder Workshops, and are listed here in descending order of effectiveness and feasibility. Note: Risk mitigation options are possibilities for risk mitigation and should not be confused with recommendations for action (which are listed below).

- Use exclusion fencing, alone or in conjunction with road-crossing structures, to prevent koalas from crossing roads (CCP16).
- Manage "black spots" for koala motor vehicle trauma in a similar fashion to school zones, with speed restrictions, cameras and heavy fines for non-compliance (CCP17).
- Seek timely, location-specific input from koala advisors on koala behaviour and movement patterns for road design projects (CCP16 and CCP17).
- Undertake education programs to inform and engage the community about road risks to koalas and promote change of vehicle driver behaviours to reduce risk (CCP17).
- Use koala road warning signs. “Smart” signs, which illuminate in response to motorist speed, or in the presence of tagged koalas in the area, may be more effective than “static” signs (CCP17).
- Increasing roadside visibility in black spots e.g. vegetation clearing, lighting etc (CCP17).
- Use structures such as climbing partitions, wildlife bridges, escape ramps and underpasses, to enable safer road crossing for koalas (CCP16).
- Avoid building new roads close to existing high-value koala habitat (CCP16 and CCP17).
- Apply speed limits or build speed modification structures such as roundabouts in identified “black spot” areas, to significantly slow approaching traffic to reduce likelihood and severity of koala road trauma (CCP17).
- Alter patterns of road use to reduce overlap of high traffic with high frequency of koala road crossing (CCP17).
- Strengthen existing habitat corridors and restore habitat connectivity which has been lost, through re-vegetation and restoration projects (CCP1).
- Focus on modifying existing roads to carry more traffic rather than building more roads (CCP16 and CCP17).
- Advise on strategies to reduce risks of koala dispersal towards roads during timber harvesting (CCP17).
- Strengthen regulatory controls against habitat clearing and road development in koala habitat and dispersal corridors (CCP1).
- Re-vegetation, restoration and preservation of habitat, including in urban landscapes (CCP1).

5.7.6 Recommendations

Recommendations for motor vehicle trauma are grouped as top priority and next priority as determined through consultation during the KDRA Stakeholder Workshops.

All general recommendations listed in *Section 1.6.2* apply to motor vehicle trauma.

Hazard-specific recommendations

The following recommendations are specific to this hazard:

Top priority recommendations specific to motor vehicle trauma:

7.1 Incorporate considerations of koala ecology and behaviour into road planning and design at the onset of projects.

7.2 Develop and implement national best-practice strategies and guidelines to reduce koala motor vehicle trauma in "black spots" for koala MVA.

7.3 Implement studies to investigate the effectiveness of vehicle strike prevention strategies, including traffic modification, road-crossing structures, physical barriers and driver education and awareness.

7.4 Identify “black spots” for koala MVA across their range and focus mitigation efforts in these areas.

Next priority recommendations specific to motor vehicle trauma:

7.5 Support nationally-agreed monitoring for koalas following rehabilitation and release, to inform the long-term outcomes for koalas, and to evaluate the impact of vehicle trauma on population levels.

7.6 Implement nationally-agreed and long-term longitudinal tracking studies to improve understanding of koala movement patterns with respect to roads.

7.7 Develop nationally-agreed protocols for clinical evaluation, triage and treatment for koala trauma injuries.

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5.8 Neoplasia in Koalas – Risk Assessment

The literature review which supports this risk assessment is in *Appendix 5.8*.

5.8.1 Hazard summary

- There is a high incidence of neoplasia in koalas, relative to most other species [1-7], with the most common neoplasms being lymphoid (lymphoma, leukaemia and lymphosarcoma), craniofacial osteochondroma and mesothelioma [8-11].
- There is epidemiological and mechanistic evidence for an association between KoRV and neoplasia [1, 6, 12-19], but the association is complex, and causation has yet to be confirmed. The most likely mechanism appears to be genetic interference from KoRV genomic integrations (some of which are heritable), although KoRV-induced immune modulation may play a role.
- Neoplasia is more prevalent in northern koala populations than southern, which may reflect differences in the genetic expression and epidemiology of KoRV between northern and southern koala populations [19].
- The role of causal factors other than KoRV in neoplasia has not been explored in koalas.
- Signs of neoplasia depend on the organs involved, but commonly include lethargy, anorexia and loss of body condition [8, 11, 20].
- The prognosis is poor for the common types of neoplasia seen in koalas [3, 5, 7, 8, 11, 20, 21]. Treatment for neoplasia has mostly been ineffective in koalas, except in a small number of cases where early surgical resection of localised tumours has been successful.
- The options for prevention and control of neoplasia in koalas are focused on reducing the likely impacts of KoRV-associated effects and maintaining genetic diversity, including in restricted, inbred populations. Future work may identify additional methods of prevention and control.
- For further detail on current knowledge of this hazard, refer to *Appendix 5.8 Neoplasia in Koalas - Literature Review*.

5.8.2 Justification for hazard selection

Neoplasia is commonly reported in koalas and appears to occur at a higher prevalence than in other marsupials/ eutherians [1-7]. Neoplasia is often fatal in koalas, and treatment, control and prevention strategies have not been confirmed.

5.8.3 Identified gaps in knowledge

- Further studies are required to clarify the role of oncogenes and their interaction with KoRV viral proteins in neoplasia.
- Additional surveillance data are required to develop a more accurate picture of neoplasia prevalence in koalas.

- Other than KoRV, there is little information on the possible predisposing or causative factors for neoplasia in koalas.

5.8.4 Risk assessment

Figure 12 shows a schematic of the hazard pathways and critical control points (CCPs) identified for this hazard. Critical control points are *key* points in the hazard pathway where risk mitigation methods could be most effective (see *Appendix 2.3 Risk Assessment Methods* for further information). Nineteen CCPs (CCP1-CCP19) were identified across all hazards, but only those applicable to this hazard are described below. See *Section 6 Critical Control Points by Disease Hazard* for a summary of CCPs across all hazards selected for detailed assessment.

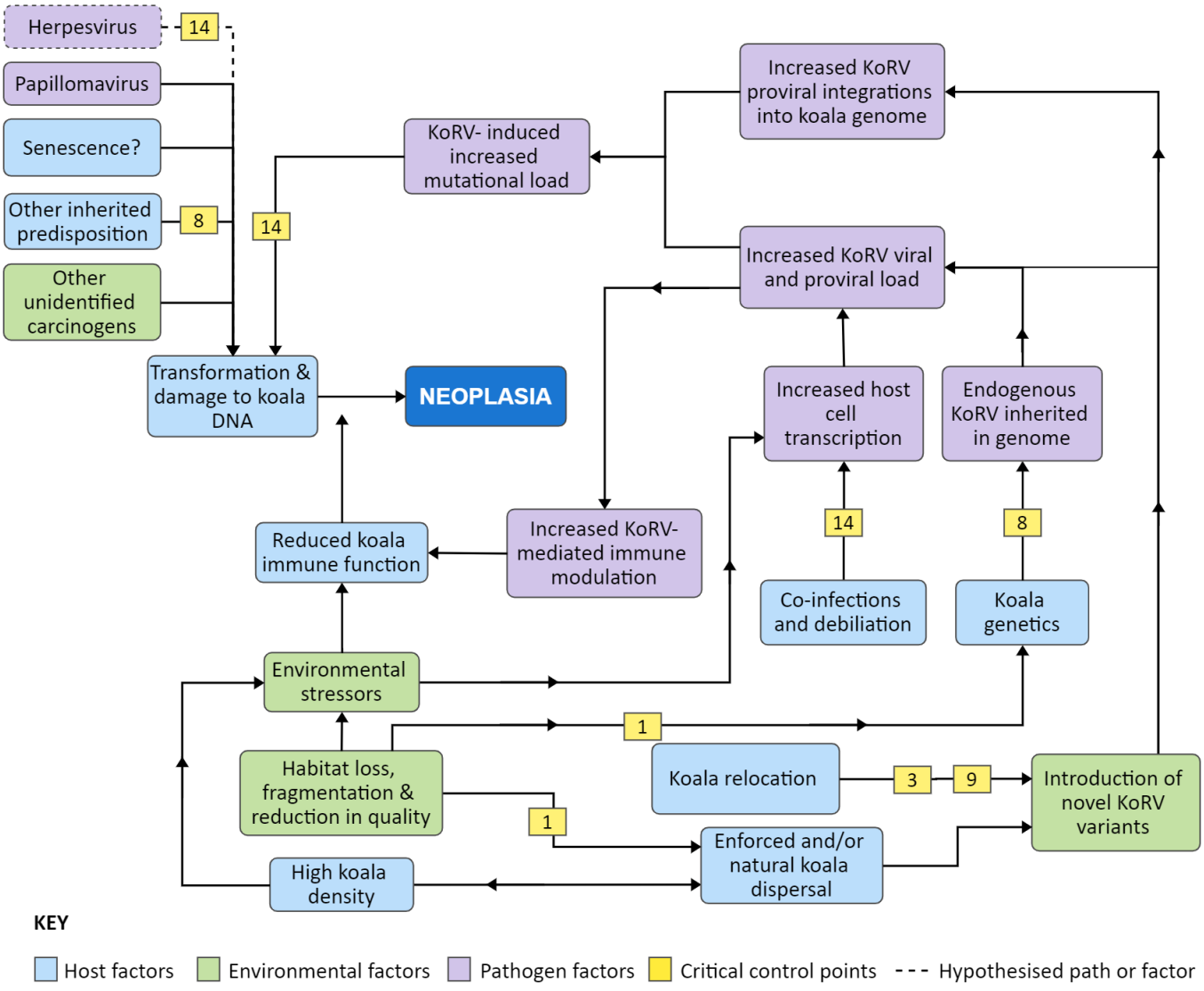

Figure 12 Hazard pathways and critical control points for neoplasia in koalas

Critical control points

CCP1 Habitat loss, fragmentation and reduction in quality

Habitat loss and reduction in habitat quality are major environmental stressors due to the koala's reliance on particular tree species for food, shelter and thermoregulation [22, 23]. Habitat fragmentation reduces connectivity between suitable koala habitat, potentially contributing to the loss of important genetic alleles in populations which can no longer interbreed [24-26] and promoting inherited predispositions to neoplasia. Causes include urban expansion, land clearing for production, inappropriate fire management practices, the introduction of pests, weeds and plant pathogens, over-browsing by koalas as a result of local overcrowding, and the habitat-altering effects of climate change [27-33].

CCP3 Koala relocation

Human-mediated movement of koalas may increase disease risk by introducing pathogens, or new pathogen varieties [34]. This may occur when koalas are brought into rehabilitation or released from rehabilitation (especially if not returned to their point of capture), when captive koalas are transferred between facilities [35], when koalas are translocated from one wild population to another [36], or when habitat corridors are created to reconnect long-separated populations without consideration of disease control.

In particular, relocated koalas that have KoRV integrations in different locations in their genomes to the resident population could increase integration site diversity in the resident population [17, 37, 38]. If those novel integrations are oncogenic, it could increase the risk of neoplasia in the population.

CCP8 Genetics

The individual koala may have a genetic predisposition to development of neoplasia. Inherited KoRV integrations in the koala genome are associated with increased neoplasia risk to koalas [12, 19], and may be responsible for a hereditary pattern for some neoplastic conditions [6]. Improving or at least maintaining genetic diversity in koala populations is likely to conserve adaptive potential [39] and encourage the retention of the most robust koala genetic profiles for avoiding inherited (including KoRV-related) susceptibility to neoplasia.

CCP9 Naïve host

An infectious pathogen may be introduced to a previously unexposed population or a previously uninfected individual.

The endogenous form of replication competent (*pol*-positive) KoRV-A has a prevalence of 100% in northern koalas [40] but appears to be absent from southern populations [41]. The introduction of replication-competent KoRV into the genome of southern populations (via breeding between *pol*-positive and *pol*-negative koalas) could increase the risk of KoRV-related neoplasia in southern populations.

Exogenous KoRV variants appear to vary in their prevalence throughout the koala's distribution [12, 15, 19, 37, 38, 42-46]. There may be the potential for transmission of exogenous variants into a population via close contact between koalas [17, 37, 47-49].

CCP14 Concurrent infections and debilitation

Concurrent infections and debilitation can compromise immune function and general health in ways that increase the risk or severity of disease.

In particular, koala host cells that are stimulated by inflammation to increase transcription or proliferate (as a result of pathogen infection or general debilitation of the host) likely increase KoRV viral and proviral load [19], resulting in more opportunities for the oncogenic effects of KoRV to be manifest in the host.

Likelihood assessment

Assessments for the likelihood of neoplasia were made only for koalas, and were not made in relation to the health and welfare of other species.

Neoplasia occurs spontaneously in all animal species. Both northern and southern koala populations report cases of neoplasia, although neoplasia is generally more prevalent in northern populations [6, 10, 19, 50-52]. Although rates of neoplasia in koalas are considered higher than expected in other mammal species [1-7], most koalas do not develop neoplasia in their lifetime.

The prevalence of neoplasia in wild koala populations has not been determined, in part because there are no nationally-accepted denominator data on the size of koala populations. Studies of admissions to wildlife hospitals in Qld found 1% to 3.2% of koalas presented with neoplasia [7, 53], although these figures are likely to under-represent the numbers in the wild as most koalas with neoplasia would not be expected to come into care. Neoplasia was reported to cause approximately 55% of disease in captive koalas in Australian facilities [6].

Endogenous, replication competent KoRV (which is probably a risk factor for koala neoplasia and is present in 100% of northern koalas but appears absent in southern populations) is inherited by subsequent generations [54]. Inherited neoplasia due to factors other than KoRV may also occur in koalas. Exogenous KoRV variants may also have a mutagenic effect on the koala genome, although they are not subsequently inherited [1]. Based on neoplasia prevalence figures in northern koalas, most koalas with replication-competent (whether exogenous or endogenous) KoRV in their genome do not develop KoRV-associated neoplasia [7, 53].

There may be other unconfirmed risk factors (host, environment or pathogen related) that increase the likelihood of neoplasia developing in individual koalas, but these have not been extensively studied. The likelihood of neoplasia may be higher in genetically restricted koala populations (both in captivity and in the wild) [6].

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of a koala experiencing neoplasia during its lifetime is considered **LOW**.

Consequence assessments

Assessments for the consequence of neoplasia were made only for koalas, and were not made in relation to the health and welfare of other species.

Koala population resilience and viability

Most, but not all, cases of neoplasia in koalas are expected to result in death [3, 5, 7, 8, 11, 20, 21]. Many neoplastic conditions may occur as animals grow older and may be a part of the natural process of senescence. The lack of information on prevalence of neoplasia in wild koala populations hampers the assessment of consequence of neoplasia on koala population resilience and viability. Inherited tendency to neoplasia is likely to be more readily expressed in small, fragmented populations where inbreeding is more likely to occur [24-26, 55].

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of neoplasia to koala population resilience and viability is considered **MINOR**.

Koala individual health and welfare

Most koalas with neoplasia would be unwell. Most, but not all, cases of neoplasia in koalas are expected to result to death. Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of neoplasia to koala individual health and welfare is considered **MAJOR**.

Overall risk estimate

The overall risk of neoplasia to koala population resilience and viability, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **LOW**.

The overall risk of neoplasia to individual koalas, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **MODERATE**.

This assessment exceeds the acceptable risk thresholds for both koala populations and individual koalas as outlined in *Appendix 2.3 Risk Assessment Methods*, therefore risk management for neoplasia is recommended.

Level of confidence in risk assessment

The level of confidence in the likelihood assessment is considered **MEDIUM**. Neoplasia is known to spontaneously occur in all animals and is well documented in both northern and southern koala populations. However, the prevalence of neoplasia in wild koala populations has not been determined and there are no accurate denominator data on the size of koala populations. The level of confidence in the consequence assessment is considered **MEDIUM**.

The disease and welfare impacts of neoplasia on the individual koala are well documented, however, there is limited data on the demographics of neoplasia in wild koala populations, which will influence the population effects of this disease.

Overall, the confidence in the risk estimate for neoplasia is considered **MEDIUM**.

5.8.5 Risk mitigation options

The following risk mitigation measures have been identified for neoplasia. Further information and justification can be found in the *Treatment* and *Prevention and control* sections of the *Neoplasia - Literature Review* chapter. Risk mitigation options were assessed for both effectiveness and feasibility during KDRA Stakeholder Workshops, and are listed here in descending order of effectiveness and feasibility. Note: Risk mitigation options are possibilities for risk mitigation and should not be confused with recommendations for action (which are listed below).

- Given the likely role of KoRV as a risk factor for koala neoplasia, risk mitigation options applicable to KoRV may also mitigate neoplasia risk (*see Section 5.2 Koala Retrovirus – Risk Assessment*) (CCP3, CCP8, CCP9 and CCP14)
- Minimise breeding or translocating from koala populations or family lines with a high prevalence of neoplasia (CCP8).
- Re-vegetation, restoration and preservation of habitat, including in urban landscapes (CCP1 and CCP8).
- Undertake localised actions, informed by improved data from particular neoplasia case clusters in koalas (CCP3, CCP8, CCP9 and CCP14).
- Strengthen regulatory controls against habitat clearing and road development in koala habitat and dispersal corridors (CCP1 and CCP8).
- Support genetic diversity in koala populations to encourage the retention of the most robust koala genetic profiles for avoiding inherited neoplastic predisposition (CCP8).

5.8.6 Recommendations

Recommendations for neoplasia are grouped as “top priority” and “next priority” as determined through consultation during the KDRA Implementation Workshops.

All general recommendations listed in *Section 1.6.2* apply to neoplasia.

Hazard-specific recommendations

The following recommendations are specific to this hazard:

Top priority recommendations specific to neoplasia:

8.1 Investigate the role of host genetics in the development of neoplasia.
8.2 Further investigate association between neoplasia and KoRV.

Next priority recommendations specific to neoplasia:

8.3 Investigate associations between neoplasia and other potential oncogenic agents, particularly PhaHV.

8.4 Identify populations or families with increased prevalence of neoplasia, so targeted risk mitigation can occur.

8.5 Incorporate understanding of inherited predisposition to neoplasia into breeding and translocation decision-making.

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5.9 Sarcoptic Mange in Koalas – Risk Assessment

The literature review which supports this risk assessment is in *Appendix 5.9*.

5.9.1 Hazard summary

- Sarcoptic mange is a skin disease caused by the parasitic mite *Sarcoptes scabiei* [1].
- Sarcoptic mange is an emerging disease issue for free-ranging koalas [2].
- Sarcoptic mange has been identified most frequently in koalas in Vic and SA [3-7], although there are also unpublished reports of sporadic cases in NSW and Qld [8].
- Sarcoptic mange can have severe impact on the health and welfare of individual koalas [3].
- The epidemiology of sarcoptic mange in Australian wildlife is variably understood among impacted species [1] and no systematic studies of the epidemiology in koalas have been undertaken.
- Recent studies are improving understanding of the safety and efficacy of antiparasiticals for koalas [7, 9-11], although current sarcoptic mange treatment regimens for koalas in rehabilitation are commonly based on extrapolation from treatment in other species or humans.
- More information on the parasite's epidemiology in relation to koalas is needed to advise the development of effective protocols.
- For further detail on current knowledge of this hazard, refer to *Appendix 5.9 Sarcoptic Mange in Koalas - Literature Review*.

5.9.2 Justification for hazard selection

Sarcoptic mange is a disease of emerging significance in an increasing number of wildlife species, including koalas in Australia [2, 12, 13] . Outbreaks are reported with increasing frequency in free-ranging koalas, particularly in southern populations, and affected animals can suffer severe, debilitating illness [3, 4].

5.9.3 Identified gaps in knowledge

- Information on the prevalence and distribution of *Sarcoptes scabiei* is variable among host species in Australia. A nationally coordinated approach to investigations of this emerging disease is required [1].
- The transmission pathways leading to *S. scabiei* infection in koalas are poorly understood. More epidemiological investigation is required to confirm whether sustained koala-to-koala transmission occurs, or if cases in koalas arise from repeated transmission from other species or the environment [14].
- Specific information on the prevalence and distribution of sarcoptic mange in free-ranging koalas, and the natural progression of *S. scabiei* infection in koalas, is required to enable evaluation of associated risk.

- Study of disease associations is required to determine whether co-infections such as KoRV, PhaHV and *Chlamydia* might affect the koala's susceptibility to sarcoptic mange, or conversely, whether debilitation caused by sarcoptic mange increases disease expression or susceptibility to other koala disease hazards.
- A scientifically validated, systematic approach to treatment of mange in koalas is required [1]. There is a need for further pharmacokinetic research, integration of the experiences of wildlife volunteers and rehabilitators, and investigation of post-treatment monitoring strategies for koalas, drawing on knowledge of mange treatment in other wildlife species.
- Strategies for control and prevention of sarcoptic mange in free-ranging koala individuals and populations require development [15].

5.9.4 Risk assessment

Figure 13 shows a schematic of the hazard pathways and critical control points (CCPs) identified for this hazard. Critical control points are *key* points in the hazard pathway where risk mitigation methods could be most effective (see *Appendix 2.3 Risk Assessment Methods* for further information). Nineteen CCPs (CCP1-CCP19) were identified across all hazards, but only those applicable to this hazard are described below. See *Section 6 Critical Control Points by Disease Hazard* for a summary of CCPs across all hazards selected for detailed assessment.

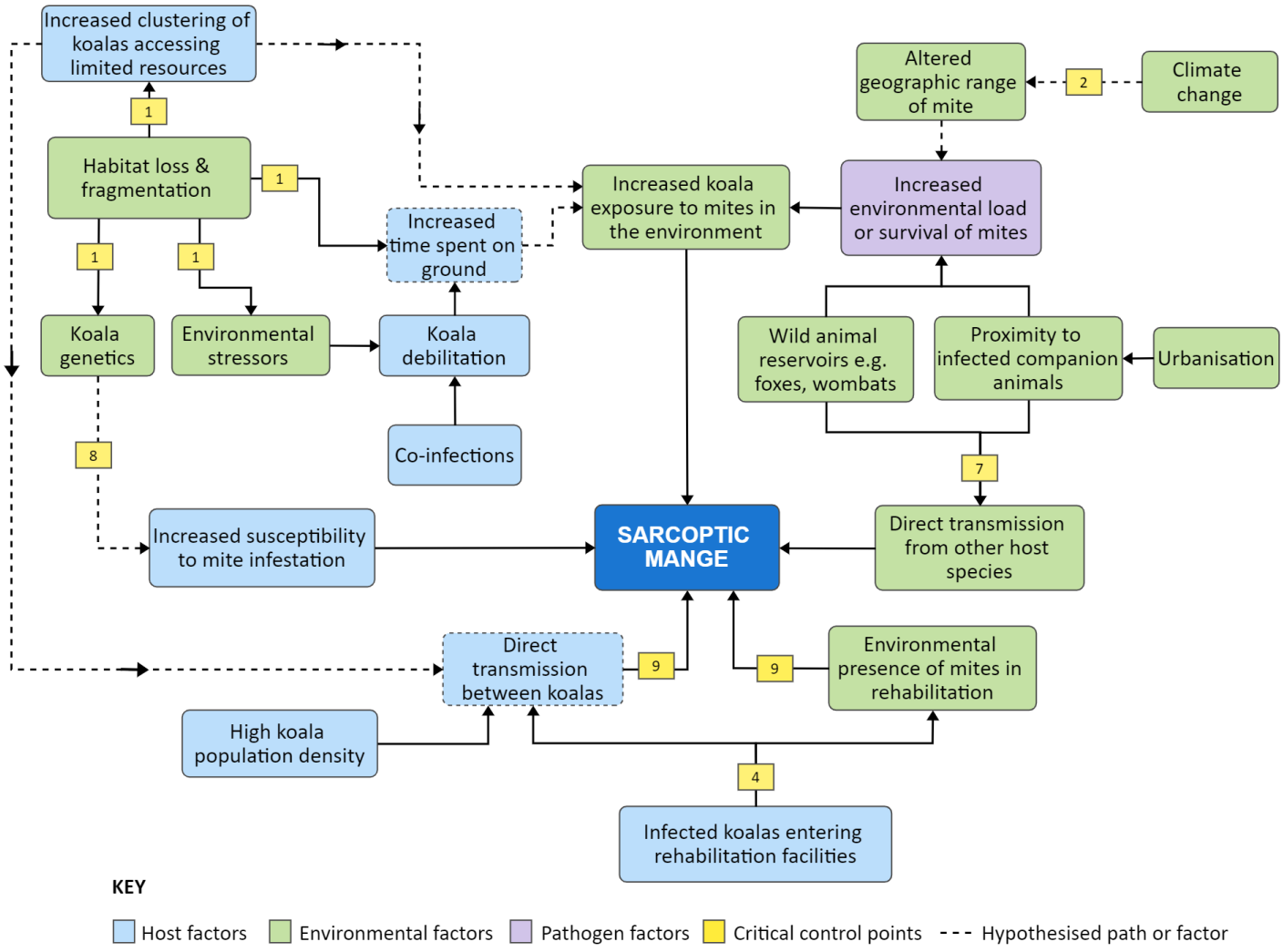

Figure 13 Hazard pathways and critical control points for sarcoptic mange in koalas

Critical control points

CCP1 Habitat loss, fragmentation and reduction in quality

Habitat loss and reduction in habitat quality are major environmental stressors due to the koala's reliance on particular tree species for food, shelter and thermoregulation [16, 17]. Habitat fragmentation reduces connectivity between suitable koala habitats, forcing dispersal and potentially contributing to the loss of important genetic alleles in populations that can no longer interbreed [18-20]. This may increase koala exposure to mites in the environment, by increasing the amount of time spent on the ground, in contact with substrates infected by reservoir species. Loss of habitat connectivity also leads to increased clustering of koalas [21], which could increase mite transmission if direct koala-to-koala contact is a significant transmission pathway [3]. Causes include urban expansion, land clearing for production, inappropriate fire management practices, the introduction of pests, weeds and plant pathogens, over-browsing by koalas as a result of local overcrowding, and the habitat-altering effects of climate change [21-27].

CCP2 Environmental stressors

Stressors in the koala's environment (in the wild or in captivity) contribute to general debilitation of the host, reduced immune function, and increased susceptibility to disease or severity of disease expression [17, 28-30]. Major environmental stressors for koalas include habitat loss, fragmentation and reduction in quality; nutritional stress; climate change; extremes of weather and disturbance related to human activities [16, 31].

Changing climate may result in an increased or altered geographic range for the *Sarcoptes* mite in Australia.

CCP4 Biosecurity practices

Biosecurity practices aim to ensure that infected koalas (or those of unknown infection status) do not pose a risk to other koalas in the population (captive or wild). Biosecurity practices may include quarantine of incoming or outgoing animals, appropriate use of personal protective equipment, general hygiene, prophylactic treatment and disinfection practices [32].

Koalas which are infected with mange may infect other animals in rehabilitation if biosecurity practices are inadequate.

CCP7 Disease reservoirs in other species

Pathogens may be present through other host species with a risk of spillover to koalas. Foxes and wombats are possible (but unconfirmed) reservoirs of sarcoptic mange infection to koalas [3, 14, 33].

CCP8 Genetics

The individual koala may have a genetic predisposition to the development of disease or increased severity of disease. Improving or at least maintaining genetic diversity in koala populations is likely to conserve adaptive potential [34] and encourage the retention of the most robust koala genetic profiles to avoid disease consequences of sarcoptic mange.

CCP9 Naïve host

An infectious pathogen may be introduced to a previously unexposed population or a previously uninfected individual. Koalas may contract *S. scabiei* through environmental presence of the mite or through direct contact with infected koalas [35].

Likelihood assessments

Likelihood of entry and exposure of koalas was considered for “koala population to koala population” and “other animal population to koala population” transmission pathways. Likelihood of an infected koala causing a hazard to humans or other animals (via their exposure to koalas or koala environments) was also evaluated.

Entry assessment - koalas

Sarcoptic mange cases have been reported in koalas or other species throughout the koala's distribution [36-40], suggesting that the mites are potentially present wherever koalas are found.

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of *Sarcoptes scabiei* entering, or being present, in environments where koalas are found is considered to be **HIGH**.

Exposure assessment - koalas

The means by which koalas are exposed to *S. scabiei* mites is unknown. Contact with trees or substrate containing mites has been suggested [3]. It has not been determined if koala-to-koala transmission occurs, but transmission through sharing of habitat with reservoir species such as foxes and wombats is suspected to be a means of exposure [3, 33, 36].

The prevalence of *S. scabiei* in koala populations is not known and reports have been limited to localised outbreaks in a small number of koala populations in Vic and SA [3, 4]. Prevalence in one outbreak in SA was estimated at 8% [4], with a 3-4% prevalence of sarcoptic mange in mortality studies of Vic and SA koalas [5, 41]. These figures are similar to prevalence reported in wombats, where *S. scabiei* is endemic [42].

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of exposure to *S. scabiei* for an individual koala is considered **LOW**.

Using the principles of combining entry and exposure likelihood as outlined in *Appendix 2.3 Risk Assessment Methods*, the combined likelihood of entry and exposure for *S. scabiei* for koalas is considered **LOW**.

Likelihood assessments - other species exposed to koalas

Koalas have not been identified as a reservoir species for *S. scabiei* in the wild. The sporadic and isolated nature of sarcoptic mange outbreaks in koalas suggests that they do not significantly increase the risk of sarcoptic mange entry or exposure to other species (including humans) in the free-ranging environment. In the captive or rehabilitation environment, affected koalas could be responsible for exposure of humans and other captive animals to *S. scabiei*, although this is considered unlikely. There are no reports of koalas passing *S. scabiei* infection on to other non-human species, and there has only been one report of a human possibly acquiring *S. scabiei* infection (scabies) from exposure to an infected koala [43]. While reports of cross-infection from koalas are limited, evidence from all other species suggests that transmission to humans is possible.

The likelihood of a human or other animal species being exposed to *S. scabiei* as a result of free- ranging koala infection is considered **NEGLIGIBLE** unless koalas are being handled directly by humans during field procedures, where the risk is considered **LOW**. The

likelihood of a human or other animal species being exposed to *S. scabiei* as a result of koala infection is considered **LOW** for the captive or rehabilitation environment. Since the likelihood of a human or other animal species being exposed to *S. scabiei* as a result of koala infection, in free-ranging populations, was evaluated as negligible in all cases except humans undertaking direct handling of koalas in the field, the risk estimate for this aspect of the hazard analysis was classified as negligible (see *Appendix 2.3 Risk Assessment Methods*) and risk assessment was only continued for the specific scenario where humans are handling koalas directly in the field. Note, however that the level of confidence in this aspect of the risk estimate (see below) is LOW.

Consequence assessments

It is not known how many cases of exposure to *S. scabiei* result in infection, nor how many cases of infection with *S. scabiei* result in clinical disease, in koalas. However, based on what is known of *S. scabiei* epidemiology in other species, and using the precautionary principle, we assume that most cases of exposure result in infection and most cases of infection result in clinical disease.

Koala population resilience and viability

Population impacts of sarcoptic mange in koalas are not known. In southern populations, outbreaks of sarcoptic mange in wild koalas appear to be increasing in frequency and distribution but appear localised in their effect [3, 4, 41]. Cases of sarcoptic mange in northern populations appear to be sporadic and isolated in nature and population-level outbreaks have not been reported [8].

The consequences for populations were evaluated based on the most severe impacts observed in koalas to date, consistent with the precautionary principle.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of *S. scabiei* infection to koala population resilience and viability is considered **MINOR**.

Koala individual health and welfare

Chronic sarcoptic mange in koalas is associated with severe debilitation and often death [3]. It is not known how many cases of exposure to *S. scabiei* result in infection and it is not known whether koalas can mount an effective immune response to clear *S. scabiei* infection, rather than developing sarcoptic mange. However, on the basis of the precautionary principle, it is assumed that koalas which are exposed to *S. scabiei* generally develop sarcoptic mange.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of *S. scabiei* infection to koala individual health and welfare is considered to be **MAJOR.**

Health and welfare – humans and other species

Evaluation of the overall consequences of sarcoptic mange in koalas for individuals of other species incorporated the fact that exposure to koalas (or their environments) has rarely been reported to lead to disease in other species, as well as the consequences for individual health and welfare for the small proportion in which disease might occur.

Scabies in humans is generally a mild and self-limiting condition, although severe disease can occur [44-46] . Sarcoptic mange in other species can range from mild to severe [12].

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of koala *S. scabiei* infection to health and welfare of humans and of other species is considered to be **MINOR**.

Overall risk estimate

The overall risk of *S. scabiei* infection to koala population resilience and viability, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **LOW**.

The overall risk of *S. scabiei* infection to individual koala health and welfare, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **MODERATE**.

The overall risk of *S. scabiei* infection of koalas to human health and welfare, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods,* is **LOW** in the captive and rehabilitation environment, and also **LOW** if humans are directly handling free-ranging koalas.

The overall risk of *S. scabiei* infection of koalas to health and welfare of other species, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **LOW** in the captive and rehabilitation environment.

This assessment exceeds the acceptable risk thresholds as outlined in *Appendix 2.3 Risk Assessment Methods* for koala populations and individual koalas, and also for other species and human health in the captive and rehabilitation environment. Therefore, risk management for sarcoptic mange in these situations is recommended.

Level of confidence in risk assessment

Knowledge of the epidemiology of *S. scabiei* in koalas is limited. The level of confidence in the entry assessment for koalas is considered **HIGH** because *S. scabiei* has been identified regularly throughout koala habitats. The level of confidence in the exposure assessment for koalas is considered **LOW** because there is little information on the ways by which koalas become exposed to the mite. The role of koalas in the maintenance of *S. scabiei* load in environments has not been explored and therefore the level of confidence in the likelihood of exposure of other species as a result of koala infection is considered **LOW**.

It is not known how many cases of exposure to *S. scabiei* result in infection in koalas, nor how many cases of infection with *S. scabiei* result in clinical disease. There is no information on prevalence of *S. scabiei* in koala populations, nor on the ability of koalas to clear infection

naturally. Therefore, the level of confidence in the consequence assessments for koala populations is considered **LOW**.

The clinical and health impacts of sarcoptic mange on individual koalas, humans and other species have been well described. Therefore, the level of confidence in the consequence assessments for the health and welfare of individual koalas, humans and other animal species is considered **HIGH**.

Overall, the confidence in the risk estimate for *S. scabiei* infection in koalas is considered **MEDIUM**.

5.9.5 Risk mitigation options

The following risk mitigation measures have been identified for *S. scabiei* infection in koalas. Further information and justification can be found in the *Treatment* and *Prevention and control* sections of the relevant literature review chapter. Risk mitigation options were assessed for both effectiveness and feasibility during KDRA Stakeholder Workshops, and are listed here in descending order of effectiveness and feasibility. Note: Risk mitigation options are possibilities for risk mitigation and should not be confused with recommendations for action (which are listed below).

- Undertake surveillance for sarcoptic mange in koala populations where outbreaks are known to occur, allowing early detection of clinical cases and treatment in rehabilitation or while remaining in the wild (CCP9).
- Practise barrier hygiene between animals of different disease status in captivity and in rehabilitation (CCP4).
- Control feral animal reservoirs (particularly foxes) (CCP7).
- Implement biosecurity practices specific to sarcoptic mange risk for koalas entering rehabilitation, and for field procedures where koalas are being directly handled (CCP4).
- Re-vegetation, restoration and preservation of habitat, including in urban landscapes, to reduce clustering of koalas around limited resources which may increase mite transmission (CCP1).
- Reduce impact of climate change on mite geographic range and persistence by supporting actions to bring about “climate-friendly” policies at a local, state and federal level (CCP2).
- Prevent cross-contamination, zoonotic transmission and transmission to other species through appropriate disinfection, personal protective equipment and equipment use (CCP4).
- Control sarcoptic mange in susceptible species, such as wombats, that share koala habitat (CCP7).
- Support regulations and education programs to control domestic dog interactions with koalas (CCP7).

- Support genetic diversity in koala populations to encourage the retention of the most robust koala genetic profiles for avoiding serious consequences of infection with *S. scabiei* (CCP8).
- Use koalas and their plight as a focus-point for community education about climate change and a "call to action" for associated behaviour change (CCP2).

5.9.6 Recommendations

Recommendations for sarcoptic mange are grouped as "top priority" and "next priority" as determined through consultation during the KDRA Stakeholder Workshops.

All general recommendations listed in *Section 1.6.2* apply to sarcoptic mange.

Hazard-specific recommendations

The following recommendations are specific to this hazard:

Top priority recommendations specific to sarcoptic mange:

9.1 Investigate the epidemiology of sarcoptic mange in koalas to identify species-specific drivers for disease.

9.2 Collect and collate standardised records of clinical signs and response to treatment of sarcoptic mange in koalas to enable evidence-based evaluation of treatment regimens.

9.3 Investigate the pharmacokinetics of antiparasitic medications in koalas, to enable selection of the safest and most effective drugs for treating sarcoptic mange.

Next priority recommendations specific to sarcoptic mange:

9.4 Develop nationally-agreed protocols for triage and treatment of koalas with sarcoptic mange.

9.5 Implement biosecurity practices specific to sarcoptic mange risk for koalas entering rehabilitation, and for field procedures.

5.9.7 References

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5.10 Oxalate Nephrosis in Koalas – Risk Assessment

The literature review which supports this risk assessment is in *Appendix 5.10*.

5.10.1 Hazard summary

- Oxalate nephrosis (ON) is a significant cause of morbidity and mortality in some wild koala populations, notably the Mount Lofty Ranges (MLR) population in SA [1, 2].
- A genetic predisposition to the development of ON is likely in the populations where it is most common [3, 4], with disease expression potentially affected by a range of factors, including patient hydration status and gastrointestinal microflora [5-7], and oxalate and moisture content of browse [8].
- Additional regions of increased prevalence of ON in free-ranging koalas have recently been identified in Vic [4]. Oxalate nephrosis in Qld and NSW most commonly develops in wild koalas during rehabilitation and is rarely diagnosed in free-ranging animals [9, 10].
- Oxalate nephrosis also occurs in captive koalas [4, 10-14].
- Animals with ON have compromised renal function which can progress to renal failure [15].
- Treatment is generally unsuccessful in advanced cases of ON, however episodes of illness in captive animals can be managed long-term with fluid therapy, optimisation of nutrition and minimization of stress [7].
- Reduction of risk of ON in captive and rehabilitation koalas involves supportive strategies to promote hydration and food intake and to minimise stress [7, 16].
- For further detail on current knowledge of this hazard, refer to *Appendix 5.10 Oxalate Nephrosis in Koalas - Literature Review.*

5.10.2 Justification for hazard selection

Oxalate nephrosis is a leading cause of disease in the MLR population of SA [1], and may be increasing in prevalence in other parts of the koala's distribution [4]. The disease is often fatal, and its development is associated with a number of non-disease risk factors which threaten koalas, including loss of genetic diversity, loss of habitat quality and quantity, and environmental stress.

5.10.3 Identified gaps in knowledge

- Further investigation into the genetic basis for ON is required [3, 4].
- Investigation of ON in koala populations beyond MLR is required, both within and outside SA, to better understand the risk factors associated with disease development in the wild and in rehabilitation.
- Controlled pharmacokinetic studies and clinical trials are required to determine safe and effective therapeutic agents for treating ON cases.

5.10.4 Risk assessment

Figure 14 shows a schematic of the hazard pathways and critical control points (CCPs) identified for this hazard. Critical control points are *key* points in the hazard pathway where risk mitigation methods could be most effective (see *Appendix 2.3 Risk Assessment Methods* for further information). Nineteen CCPs (CCP1-CCP19) were identified across all hazards, but only those applicable to this hazard are described below. See *Section 6 Critical Control Points by Disease Hazard* for a summary of CCPs across all hazards selected for detailed assessment.

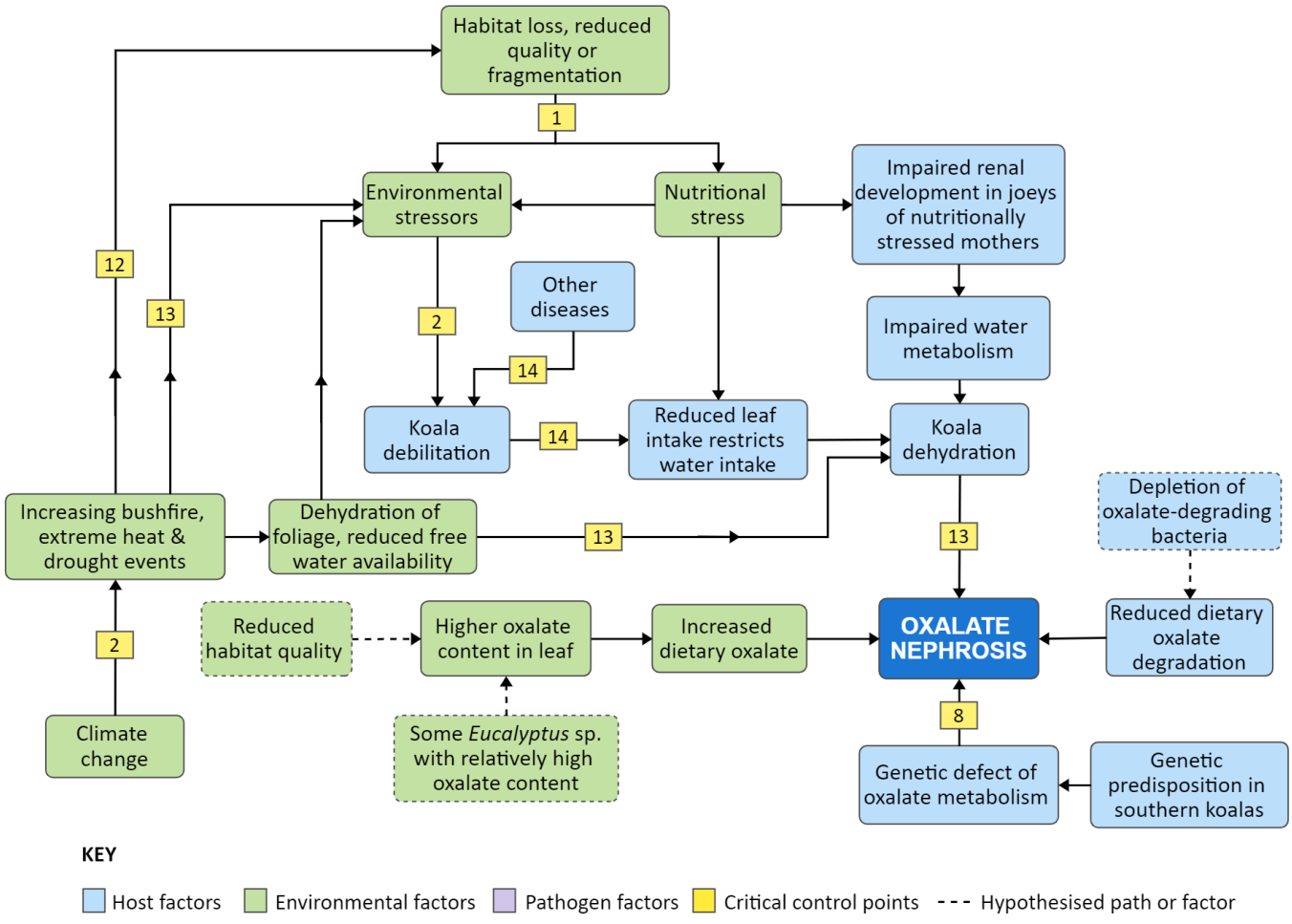

Figure 14 Hazard pathways and critical control points for oxalate nephrosis in koalas

Critical control points

CCP1 Habitat loss, fragmentation and reduction in quality

Habitat loss and reduction in habitat quality are major environmental stressors due to the koala's reliance on particular tree species for food, shelter and thermoregulation [17, 18]. Habitat fragmentation reduces connectivity between suitable koala habitats, forcing dispersal and potentially contributing to the loss of important genetic alleles in populations

that can no longer interbreed [19-21]. Causes include urban expansion, land clearing for production, inappropriate fire management practices, the introduction of pests, weeds and plant pathogens, over-browsing by koalas as a result of local overcrowding, and the habitat-altering effects of climate change [22-28].

Habitat loss, reduction and fragmentation result in loss of refugia for koalas, increasing the risk of dehydration which can promote the development of ON, particularly in hot weather [5].

CCP2 Environmental stressors

Stressors in the koala's environment (in the wild or in captivity) contribute to general debilitation of the host, reduced immune function, and increased susceptibility to disease or severity of disease expression [18, 29-31]. Major environmental stressors for koalas include habitat loss, fragmentation and reduction in quality; nutritional stress; climate change; extremes of weather and disturbance related to human activities [17, 32].

Koalas obtain about 75% of their water intake from the foliage they feed on [33]. A reduction in food (and therefore water) intake due to ill health, injury or other stress, may increase the risk of dehydration, which in itself is a source of physiological stress [32], as well as increasing the risks of ON [5].

CCP8 Genetics

The individual koala may have a genetic predisposition to development of disease or to increased severity of disease. Improving or at least maintaining genetic diversity in koala populations is likely to conserve adaptive potential [34] and encourage the retention of the most robust koala genetic profiles to avoid disease consequences.

In particular, koalas predisposed to developing ON are postulated to have genetic predisposition to abnormal oxalate metabolism [4, 35].

CCP12 Fire management practices

Inadequate planning, inappropriate methodology or flawed execution of fire management practices may contribute to habitat loss and reduction of habitat quality, reducing refugia options for koalas during heat events [36, 37] which may predispose koalas to dehydration and ON.

CCP13 Reduced water intake

In hot weather, koalas may experience reduced water intake due to lower leaf moisture content and lower free water availability (artificial or natural sources) for drinking [22, 38].

In particular, reduced water intake exacerbates renal stress and promotes the development of ON in both free-ranging and captive koalas [5, 16].

CCP14 Concurrent infections and debilitation

Concurrent infections and debilitation can compromise immune function and general health in ways that increase the risk or severity of disease. Any disease process that leads to debilitation and inappetence will contribute to koala dehydration and potentially increase susceptibility to ON [5, 16].

Likelihood assessments

Due to the higher reported prevalence of oxalate nephrosis [1, 2], the MLR koala population is considered separately to the rest of the koala population in assessment of likelihood for this hazard.

The prevalence of oxalate nephrosis appears variable across the koala's distribution. It is commonly reported in the MLR koala population [1, 39, 40] and recent studies suggest a high prevalence in some wild Vic populations [4]. In northern populations, it arises most commonly in wild koalas after they enter rehabilitation [10, 12, 15, 41-45].

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of an individual koala being affected by oxalate nephrosis is considered **LOW**, with the exception of the MLR population, where the likelihood is considered **MODERATE**.

Consequence assessments

Oxalate nephrosis is a non-infectious hazard and therefore consequence assessments were not made in relation to the health and welfare of other species or humans.

Koala population resilience and viability

Oxalate nephrosis is a leading cause of mortality in koala admissions to rehabilitation from the MLR koala population. The levels of mortality due to oxalate nephrosis could be sufficient to drive decline in the MLR population.

Koalas predisposed to developing oxalate nephrosis are hypothesised to have a genetic predisposition to abnormal oxalate metabolism [4, 35]. This is likely a factor in the high prevalence of oxalate nephrosis in MLR koalas. Other regions of increased prevalence, that may also have a genetic basis, are emerging in Vic [4]. The impact of oxalate nephrosis to population resilience and viability is likely to be significantly lower in other koala populations.

Adopting the precautionary principle, the prevalence of oxalate nephrosis in the MLR population has been used as the basis of the consequence assessment.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of oxalate nephrosis to koala population resilience and viability is considered **MINOR**.

Koala individual health and welfare

Oxalate nephrosis causes serious, and often fatal, clinical disease in affected koalas. Prognosis for recovery, even with treatment, is guarded.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of oxalate nephrosis to koala individual health and welfare is considered **MAJOR**.

Overall risk estimate

The overall risk of oxalate nephrosis to the koala populations, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods,* is **LOW**.

The overall risk of oxalate nephrosis to individual koalas, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **LOW** for individual koalas other than the MLR population. The risk of oxalate nephrosis to individual koalas in the MLR population is **HIGH**.

These risk estimates exceed the acceptable risk thresholds as outlined in *Appendix 2.3 Risk Assessment Methods* for the koala populations and for individual koalas in the MLR population.

Risk management for oxalate nephrosis is recommended for individual koalas. Given the low level of confidence in population consequence assessments (see below), risk management at the population level is recommended for the MLR population and for other koala populations where a high prevalence of oxalate nephrosis is detected in the future.

Level of confidence in risk assessment

Oxalate nephrosis is a well-recognised and readily diagnosed disease of koalas but its prevalence in free-ranging koalas is not well understood. Therefore, the level of confidence in the likelihood assessments is considered **MEDIUM**.

The impact of oxalate nephrosis to population numbers is not well studied. The level of confidence in the consequence assessments for koala populations is **LOW**.

The clinical impacts of oxalate nephrosis in koalas are well documented and understood. The level of confidence in the consequence assessments for individual koalas is **HIGH**.

Overall, the confidence in the risk estimate for oxalate nephrosis is considered **MEDIUM**.

5.10.5 Risk mitigation options

The following risk mitigation measures have been identified for oxalate nephrosis in koalas. Further information and justification can be found in the *Treatment* and *Prevention and control* sections of the relevant literature review chapter. Risk mitigation options were assessed for both effectiveness and feasibility during KDRA Stakeholder Workshops, and are listed here in descending order of effectiveness and feasibility. Note: Risk mitigation options are possibilities for risk mitigation and should not be confused with recommendations for action (which are listed below).

- For captive and rehabilitation koalas, supply free water, misting browse, and optimal management of cut browse to maintain leaf moisture (CCP1, CCP2, CCP13 and CCP19).
- Support the capacity of koalas to move to available water in their environment. This includes improving water catchment and storage via artificial or natural wetlands and slowing water outflow to increase hydration of trees, maintain moisture content of foliage and possibly reduce oxalate concentration in leaf consumed by koalas (CCP1, CCP2, CCP13 and CCP19).
- Re-vegetation, restoration and preservation of habitat, including in urban landscapes (CCP1, CCP2 and CCP13).
- Protect or develop climate refugia, such as valleys, understory, midstory and fast-growing shade-producing non-browse vegetation that provide good thermal protection for koalas and promote high moisture and nutrient content in foliage (CCP1, CCP2 and CCP13).
- Revegetate with browse and non-browse species that are drought- and heat-tolerant and suited to changing climate in the bioregion (CCP1, CCP2, CCP13 and CCP19).
- Support genetic diversity in koala populations to encourage the retention of the most robust koala genetic profiles for adapting to a changing climate and coping with the impacts of high ambient temperatures and drought. If a genetic predisposition to ON is confirmed, support of genetic diversity may reduce the perpetuation of undesirable genetic traits in koala populations (CCP8).
- Strengthen regulatory controls against habitat clearing and road development in koala habitat and dispersal corridors (CCP1, CCP2 and CCP13).
- Support soil quality and diversity, and better manage storm water run-off, to retain moisture in the soil and vegetation (CCP1, CCP2, CCP13 and CCP19).
- Act to bring about “climate-friendly” policies at a local, state and federal level (CCP1 and CCP2).
- Minimise concurrent infections, debilitation and other environmental stressors (e.g. predators, disturbance related to human activities) in koalas in captivity and in rehabilitation, which could predispose them to inappetence and dehydration and precipitate oxalate nephrosis (CCP2 and CCP14).
- Use koalas and their plight as a focus-point for community education about climate change and a “call to action” for associated behaviour change (CCP1 and CCP2).
- Plant water-retaining browse trees and tree species.(CCP1, CCP2, CCP13 and CCP19).
- Adopt fire management practices that minimise impacts on koala habitat quantity, quality and connectivity, to retain refugia from hot weather and minimise hydration stress on koalas and trees (see Risk mitigation options *in Section 5.5 Thermal Burn Trauma* for more details) (CCP12).

5.10.6 Recommendations

Recommendations for oxalate nephrosis are grouped as “top priority” and “next priority” as determined through consultation during the KDRA Stakeholder Workshops.

All general recommendations listed in *Section 1.6.2* apply to oxalate nephrosis.

Hazard-specific recommendations

The following recommendations are specific to this hazard:

Top priority recommendations specific to oxalate nephrosis:

10.1 Protect and improve koala habitat to conserve refugia and improve the quality and hydration status of koala food.

10.2 Further investigate the causes of ON in koalas including genetic risk factors and relationship to other infections and co-morbidities.

10.3 Support water retention and availability in koala environments.

Next priority recommendations specific to oxalate nephrosis:

10.4 Develop nationally-agreed protocols for prevention, assessment, treatment and care of koalas with ON in captivity and rehabilitation, including criteria for euthanasia.

10.5 Monitor the prevalence of ON across the koala's range to allow early recognition of increased prevalence outside the MLR population.

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5.11 Novel *Actinomyces* sp. in Koalas – Risk Assessment

The literature review which supports this risk assessment is in *Appendix 5.11*.

5.11.1 Hazard summary

- Bacterial pneumonia caused by a novel species of *Actinomyces* has been reported in at least 20 wild koalas from SA since 2016 [1-3]. Actinomycotic pneumonia has been reported in one koala from Qld [4].
- *Actinomyces* are anaerobic or facultative aerobic bacteria, believed to form part of the healthy gastrointestinal microbiome of many animal species including humans [5-11].
- *Actinomyces* spp. can cause slowly developing, chronic soft tissue, skeletal and pulmonary infections in humans and animals when the normal immune defence mechanisms of the host are disrupted, and the bacterium penetrates the soft tissues of the host [5, 6, 8, 10, 12-19].
- The initiating factors for actinomycotic pneumonia in SA koalas are not known, but aspiration of plant material (perhaps alimentary tract contents) may be involved, and dental disease has been proposed as a contributing factor [3].
- Treatment of affected koalas has not been attempted and all koalas have died or been euthanased [3].
- Treatment of actinomycosis in other species requires prolonged antibiotic treatment and carries a guarded prognosis [20, 21].
- Methods of prevention and control for pulmonary actinomycosis in koalas have not been identified [3].
- For further detail on current knowledge of this hazard, refer to *Appendix 5.11 Novel Actinomyces sp. in Koalas – Literature Review*.

5.11.2 Justification for hazard selection

Novel *Actinomyces* sp. is a recently identified pathogen of koalas and has caused severe pneumonia, generally progressing to death, in a small number of SA animals [3].

5.11.3 Identified gaps in knowledge

- Confirmation of novel *Actinomyces* sp. as a part of the healthy gastrointestinal microbiome of koalas, and an understanding of whether this organism is present in all koala populations.
- Understanding of the initiating factors which allow development of actinomycotic pneumonia in koalas is needed. The possible association with dental disease needs investigation.
- Identification of possible prevention, control and treatment methods for actinomycotic pneumonia in koalas is needed.
- Investigation is required to determine possible host genetic predispositions in affected koala populations to development of actinomycotic pneumonia.

- Identification of associations or causality between actinomycotic pneumonia and other recognised diseases of koalas is required.

5.11.4 Risk assessment

Figure 15 shows a schematic of the hazard pathways and critical control points identified for this hazard. Critical control points (CCPs) are defined as *key* points in the hazard pathway where risk mitigation methods could be most effective (see *Appendix 2.3 Risk Assessment Methods* for further information). Nineteen CCPs (CCP1-CCP19) were identified across all hazards, but only those applicable to this hazard are described below. See *Section 6 Critical Control Points by Disease Hazard* for a summary of CCPs across all hazards selected for detailed assessment.

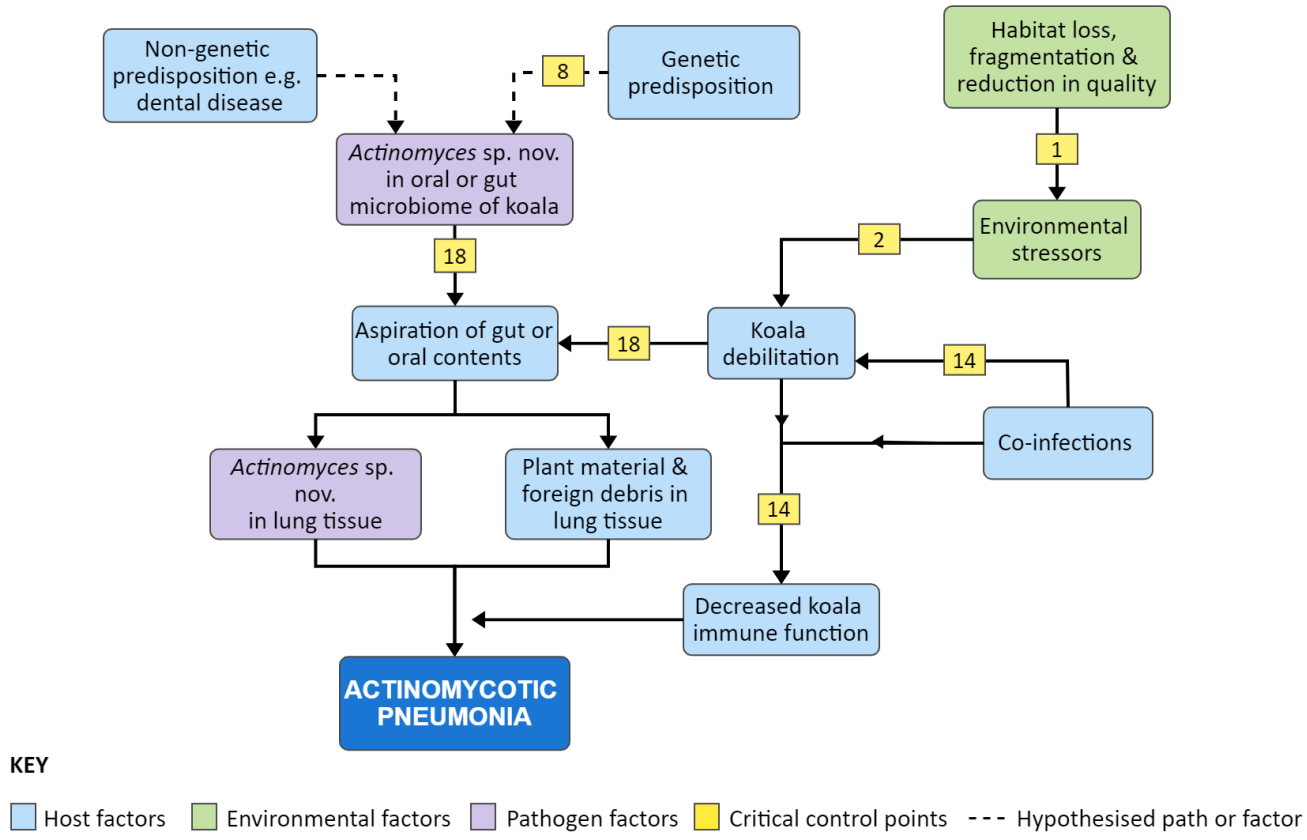

Figure 15 Hazard pathways and critical control points for actinomycotic pneumonia in koalas

Critical control points

CCP1 Habitat loss, fragmentation and reduction in quality

Habitat loss and reduction in habitat quality are major environmental stressors due to the koala's reliance on particular tree species for food, shelter and thermoregulation [22, 23]. Habitat fragmentation reduces connectivity between suitable koala habitats, forcing dispersal and potentially contributing to the loss of important genetic alleles in populations that can no longer interbreed [24-26]. Causes include urban expansion, land clearing for

production, inappropriate fire management practices, the introduction of pests, weeds and plant pathogens, over-browsing by koalas as a result of local overcrowding, and the habitat-altering effects of climate change [27-33].

CCP2 Environmental stressors

Stressors in the koala's environment (in the wild or in captivity) contribute to general debilitation, reduced immune function and increased susceptibility to disease or severity of disease expression [23, 34-36]. Major environmental stressors for koalas include habitat loss, fragmentation and reduction in quality; nutritional stress; climate change; extremes of weather and disturbance related to human activities [22, 37].

In particular, environmental stressors may contribute to general debilitation, reduced immune function and probably will increase susceptibility to *Actinomyces* infection and disease. Particular environmental stressors may increase the likelihood of koalas developing disease with *Actinomyces* if alimentary tract contents are inhaled.

CCP8 Genetics

The individual koala may have a genetic predisposition to development of disease or to increased severity of disease. Improving or at least maintaining genetic diversity in koala populations is likely to conserve adaptive potential [38] and encourage the retention of the most robust koala genetic profiles to avoid disease consequences.

Possible genetic predisposition to actinomycotic pneumonia include a lack of key immunogenetic alleles; a genetic predisposition to carrying novel *Actinomyces* sp. in the microbiome; and genetically-based anatomical differences predisposing koalas to aspiration [3].

CCP14 Concurrent infections and debilitation

Concurrent infections and debilitation can compromise immune function and general health in ways that increase the risk or severity of disease. In particular, co-infection with other pathogens might be a contributing factor to development of pulmonary actinomycosis.

CCP18 Pathogen access to target tissue

Dental disease may contribute to the initiation of pulmonary actinomycosis, as has been seen in humans [3]. Events that cause a koala to inhale gut or mouth contents or soil are believed necessary for actinomycotic pneumonia to develop. Inhalation of alimentary tract content appears likely to deposit a large load of novel *Actinomyces* sp. bacteria into the lower respiratory tract of the koala, along with a large amount of foreign organic material (plant matter). The increased load of pathogen in an abnormal site, along with foreign material, will be a strong trigger for development of bacterial pneumonia.

Likelihood assessments

As novel *Actinomyces* sp. is not considered a contagious disease, the risk of infection in other species, including humans, has not been considered.

Entry assessment

Novel *Actinomyces* sp. is assumed to be part of the normal alimentary tract flora of koalas. However, no studies have been done to confirm this, nor have studies investigated the possibility that novel *Actinomyces* sp. may be present in SA koalas but not in koalas from other populations. An unspeciated *Actinomyces* sp. was found in a koala with pneumonia in Qld. Therefore, and using the precautionary principle, this entry assessment considers that novel *Actinomyces* sp. is present, as a part of normal flora, in all koala populations.

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of actinomycotic pneumonia entering, or being present, in a koala population is considered **HIGH**.

Exposure assessment

In the circumstance of novel *Actinomyces sp.*, we assume the exposure pathway is that of an individual koala being exposed to *Actinomyces* in its lung tissue. The circumstances by which this exposure comes about are not known, but are believed to be associated with inhalation of alimentary tract contents. The reported cases of actinomycotic pneumonia in koalas are low, and it has only been detected in one state (SA) [3]. The likelihood of an individual koala being exposed to novel *Actinomyces* sp. in the lung tissue appears to vary according to geographic location, and the reasons for this are not understood. It is considered very unlikely that a healthy koala would inhale food material, and the reason this occurs, in the development of actinomycotic pneumonia, is not known.

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of exposure to novel *Actinomyces* sp. in the lung tissue for an individual koala is considered **LOW**.

Using the principles of combining entry and exposure likelihood as outlined in *Appendix 2.3 Risk Assessment Methods*, the combined likelihood of entry and exposure for actinomycotic pneumonia is considered **LOW**.

Consequence assessments

Most, if not all, koalas exposed to novel *Actinomyces* sp. in the lung tissue are likely to develop actinomycotic pneumonia, but the severity of disease in all cases is not known. By the precautionary principle, we assume that all koalas that inhale novel *Actinomyces* sp. into lung tissue will develop pneumonia.

Koala population resilience and viability

There is no information available on the likely impact of novel *Actinomyces* sp. and actinomycotic pneumonia on koala population resilience and viability. Given the low numbers of case of actinomycotic pneumonia reported, in just one small area of the koala's geographic range, the population level impacts of this disease are likely to be unnoticeable.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of actinomycotic pneumonia to koala population resilience and viability is considered **NEGLIGIBLE**.

Koala individual health and welfare

If novel *Actinomyces* sp. is inhaled in sufficient quantity and possibly with accompanying foreign material, severe bacterial pneumonia ensues. Reported cases of actinomycotic pneumonia cause significant ill health and death in koalas [3].

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of actinomycotic pneumonia to koala individual health and welfare is considered **MAJOR**.

Overall risk estimate

Since the consequence of novel *Actinomyces* sp. was evaluated as negligible for koala population resilience and viability, the estimate of risk for this hazard for koala populations was also considered **NEGLIGIBLE** (see *Appendix 2.3 Risk Assessment Methods*). Note, however that the level of confidence in this risk estimate (see below) is **LOW**. The overall risk of actinomycotic pneumonia to individual koalas, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **MODERATE**.

This assessment exceeds the acceptable risk thresholds for individual koalas, as outlined in *Appendix 2.3 Risk Assessment Methods*, therefore risk management for actinomycotic pneumonia is recommended for individual koalas.

Level of confidence in risk assessment

The level of confidence in the likelihood assessment is **LOW** as there are many gaps in knowledge about novel *Actinomyces* sp., whether it is a part of the normal flora of the koala, and whether this differs geographically (or due to other variables). It is also not known how novel *Actinomyces* sp. gains entry to the lung tissue, and if by inhalation of gastrointestinal contents, what the initiating factors are for this process, or if SA koalas have a genetic predisposition to carrying novel *Actinomyces* sp., or developing actinomycotic pneumonia.

The level of confidence in the consequence assessment for populations is **LOW**, as there are few data available. The impacts on individual koalas are better understood.

Overall, the confidence in the risk estimate for actinomycotic pneumonia is **LOW**.

5.11.5 Risk mitigation options

Few specific risk mitigation measures have been identified for novel *Actinomyces* sp. Further information and justification can be found in the *Treatment* and *Prevention and control* sections of the relevant literature review chapter. Note: Risk mitigation options are possibilities for risk mitigation and should not be confused with recommendations for action

(which are listed below). Not all risk mitigation options will be currently available, feasible, universally applicable or cost-effective, but are listed here for completeness.

Currently, no prevention or control methods have been identified that are specific for actinomycotic pneumonia in koalas. A greater understanding of the pathogen epidemiology and distribution, likely initiating factors in disease development, and treatment options will assist in more effective prevention and control strategies for pulmonary actinomycosis in koalas.

General risk mitigation options will also be applicable for novel *Actinomyces* sp. These include:

- Re-vegetation, restoration and preservation of habitat, including in urban landscapes (CCP1 and CCP8).
- Strengthen regulatory controls against habitat clearing and road development in koala habitat and dispersal corridors (CCP1 and CCP8).

These measures will encourage the maintenance of larger wild koala populations with more robust genetic profiles which are more likely to withstand the pathogenic consequences of novel *Actinomyces* infection.

- Minimise concurrent infections, debilitation and other environmental stressors (e.g. predators, disturbance related to human activities) in individual koalas and populations, as sick and debilitated koalas are likely to be more at risk of aspiration (CCP2, CCP14 and CCP18).
- Promote good dental health, as dental disease may be a contributing factor to actinomycotic pneumonia (CCP14 and CCP18).
- Minimise risk of aspiration in koalas (CCP14 and CCP18).
- Support genetic diversity in koala populations to encourage the retention of the most robust koala genetic profiles to enable effective immune response to novel *Actinomyces* sp. and avoid genetically-based anatomical differences which may predispose koalas to aspiration (CCP8).

5.11.6 Recommendations

General recommendations listed in *Section 1.6.2* apply to this disease hazard. Specific recommendations for this disease hazard have not been taken through a prioritisation exercise and are listed here in no particular order.

Hazard-specific recommendations

The following recommendations are specific to this hazard:

- Further investigate the biology and epidemiology of novel *Actinomyces* sp. in koalas, including the geographic distribution of the organism, whether it is a normal part of the koala microbiome, or present in the environment, and initiating genetic and environmental factors.

- Investigate early detection and treatment options for actinomycotic pneumonia.

5.11.7 References

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5.12 Phascolarctid Herpesviruses – Risk Assessment

The literature review which supports this risk assessment is in *Appendix 5.12*.

5.12.1 Hazard summary

- Phascolarctid herpesviruses (PhaHV)-1 and -2 are gammaherpesviruses that have likely co-evolved with koalas [1].
- An alphaherpesvirus has been detected in one captive female koala with pneumonia, hepatitis and adrenalitis and concurrent lung infection with *Cryptococcus gattii* [2], tentatively named PhaHV-3.
- PhaHV have only been detected in koalas and are not considered a risk for other wildlife or humans [1].
- Once a koala is infected with herpesvirus, infection persists for life [1].
- Herpesviral infections may be latent or lytic, and re-activation of latent herpesvirus in other species has been associated with immunosuppression and stress [3, 4].
- Transmission routes for PhaHV are unconfirmed, although prevalence studies suggest that PhaHV-2 may be acquired in infancy, while PhaHV-1 may be acquired through activities related to maturation, such as breeding behaviour [5].
- PhaHV-1 and -2 have been detected in all koala populations tested to date [5-7].
- Both PhaHV-1 and -2 detection are strongly associated with concurrent chlamydial infection [5, 7, 8], and with signs of urogenital disease in male and female koalas [5, 9, 10].
- PhaHV-1 detection is associated with increased detection of KoRV, particularly in female koalas [5].
- Direct prevention and control of PhaHV infections are not considered possible in free-living koala populations because it is unlikely that exposure can be prevented [1, 5].
- Minimising stress and managing concurrent infections are important aspects of controlling herpesvirus-associated disease in koalas [1].
- Testing koalas in rehabilitation for herpesvirus, and managing individuals while in care based on their herpesvirus status, has been recommended [7].
- For further detail on current knowledge of this hazard, refer to *Appendix 5.12 Phascolarctid Herpesviruses in Koalas - Literature Review.*

5.12.2 Justification for hazard selection

PhaHV-1 and -2 have been associated with disease states and increased severity of other diseases in wild and captive koalas in Australia. Only a single case of PhaHV-3 has been reported and it is not known if the koala is the natural host of this novel virus, or if in this instance the virus spilled over from another host [2]. Therefore, PhaHV-3 was not considered further in this risk assessment.

5.12.3 Identified gaps in knowledge

- Study of the prevalence of PhaHV-1 and -2 in northern koala populations is needed.
- The expression of disease in relation to herpesvirus infection in koalas is poorly understood, including the impact of infection with more than one herpesvirus.
- Further investigation of the biology and epidemiology of herpesviruses is needed, including sites of latent and lytic infection and transmission pathways.
- Given the high incidence of lymphomas and other neoplasia in koalas, the possible association between herpesviruses and neoplasia, as seen in humans [11], requires further exploration.
- Improved understanding of the associations between viral shedding and clinical disease could be achieved through combined studies of serological assays and PCR detection of PhaHV-1 and -2. The relationships between herpesviruses and other infectious pathogens, particularly *C. pecorum* and KoRV, require investigation [5, 8].

5.12.4 Risk assessment

Figure 16 shows a schematic of the hazard pathways and critical control points identified for this hazard. Critical control points are defined as *key* points in the hazard pathway where risk mitigation methods could be most effective (see *Appendix 2.3 Risk Assessment Methods* for further information). Nineteen CCPs (CCP1-CCP19) were identified across all hazards, but only those applicable to this hazard are described below. See *Section 6 Critical Control Points by Disease Hazard* for a summary of CCPs across all hazards selected for detailed assessment.

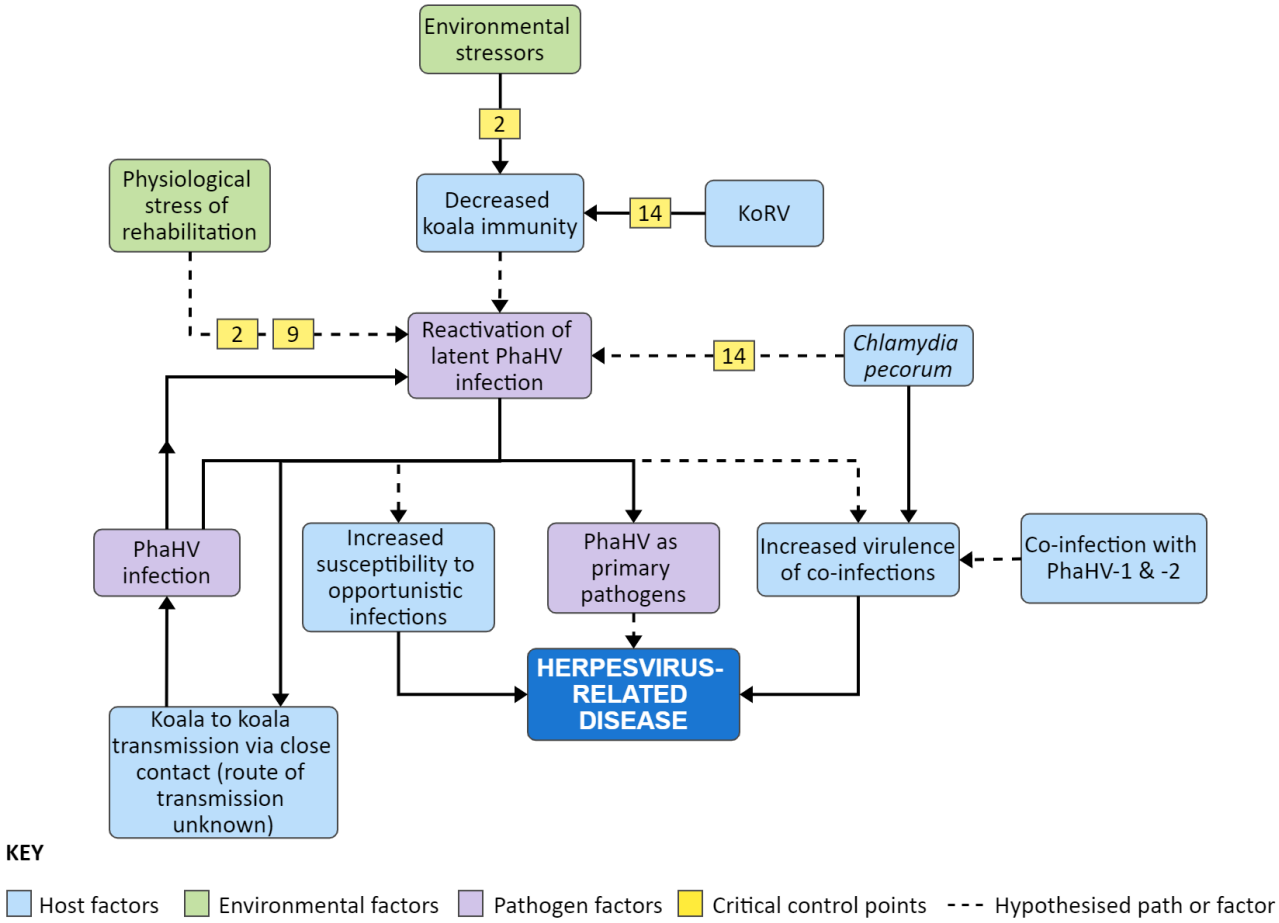

Figure 16 Hazard pathways and critical control points for phascolarctid herpesvirus-1 and -2

Critical control points

CCP2 Environmental stressors

Stressors in the koala's environment (in the wild or in captivity) contribute to general debilitation of the host, reduced immune function and increase susceptibility to disease or severity of disease expression [12-15]. Major environmental stressors for koalas include habitat loss, fragmentation and reduction in quality; nutritional stress; climate change; extremes of weather and disturbance related to human activities [16, 17].

Environmental stressors that contribute to general debilitation and reduced immune function might increase the likelihood of activation of latent PhaHV infection, with resultant disease.

CCP9 Naïve host

An infectious pathogen may be introduced to a previously unexposed population or a previously uninfected individual.

Isolation of PhaHV-positive animals in the rehabilitation environment may be advisable because of the likelihood of physiological stress in rehabilitation, which may increase likelihood of virus shedding.

CCP14 Concurrent infections and debilitation

Concurrent infections and debilitation can compromise immune function and general health in ways that increase the risk or severity of disease. The pathogenicity of an infectious hazard may be potentiated by co-infections.

Chlamydia pecorum infection could potentially reactivate latent herpesvirus infection. There are close associations between some retroviral infections and herpesvirus diseases in humans (e.g. [18]).

Likelihood assessments

Herpesviruses are host specific, so the risk of infection in other species, including humans, has not been considered.

Entry assessment

Phascolarctid herpesviruses have been found in all koala populations studied, including those which have not had introductions for over 100 years. Herpesviruses in general, and PhaHV in particular, are thought to have co-evolved with their host.

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of PhaHV-1 and -2 entering, or being present, in a koala population is considered **HIGH**.

Exposure assessment

The reported prevalence of PhaHV is moderate to high in studied koala populations, and it is assumed that this will also be the case for northern populations. It is assumed (as with other herpesviruses) that PhaHV are shed intermittently, and infection is life-long.

It is not known how frequently, for how long, and under what circumstances individual infected koalas actively shed PhaHV. It is also not known how the virus is transmitted between koalas. Both these factors (shedding, transmission route) will influence the likelihood of an individual, uninfected koala being exposed to PhaHV, or an infected koala being exposed to a different species of PhaHV.

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of exposure to PhaHV-1 and -2 for an individual koala is considered **HIGH**.

Using the principles of combining entry and exposure likelihood as outlined in *Appendix 2.3 Risk Assessment Methods*, the combined likelihood of entry and exposure for PhaHV-1 and -2 is considered **HIGH**.

Consequence assessments

Very little is known about the potential consequence of PhaHV infection at either a population or individual level. Whilst most koala populations studied to date are infected with PhaHV, ensuing disease states are not known.

Koala population resilience and viability

There is no data suggesting PhaHV causes measurable declines in koala populations, or otherwise impacts koala population resilience and viability.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of PhaHV-1 and -2 to koala population resilience and viability is considered **NEGLIGIBLE**.

Koala individual health and welfare

The impact of PhaHV-1 and -2 infection on individual koala health and welfare is not known. Several associations with clinical disease have been identified for one or both herpesviruses, including wet bottom, uterine and ovarian cysts, testicular malformation, lowered fertility in females, incidence of neoplasia, increased tooth wear and low body condition score [5, 6, 10], but causative relationships have not been established. These associations could represent reactivation and subsequent detection of herpesvirus secondary to other disease processes, rather than a primary role for herpesviruses in causing disease [5].

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of PhaHV-1 and -2 to koala individual health and welfare is considered to be **MINOR**.

Overall risk estimate

Since the consequence of PhaHV-1 and -2 was evaluated as negligible for koala population resilience and viability, the estimate of risk for this hazard for koala populations was also considered **NEGLIGIBLE** (see *Appendix 2.3 Risk Assessment Methods*). Note, however that the level of confidence in this risk estimate (see below) is LOW. The overall risk of PhaHV-1 and -2 to individual koalas, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **MODERATE**.

This assessment exceeds the acceptable risk thresholds as outlined in *Appendix 2.3 Risk Assessment Methods*, therefore risk management for PhaHV-1 and -2 is recommended for individual koalas.

Level of confidence in risk assessment

There is a **MEDIUM** level of confidence in the likelihood assessment as southern koala populations have been relatively well studied for PhaHV. However, there are no data for northern koala populations, and it is not known how frequently, for how long, and under what circumstances individual infected koalas actively shed PhaHV, nor how the virus is transmitted between koalas. There is a **LOW** level of confidence in the consequence

assessment as very little is clearly known about the potential consequence of PhaHV infection at either a populations or individual level.

Overall, the confidence in the risk estimate for PhaHV-1 and -2 is **LOW**.

5.12.5 Risk mitigation options

Few risk mitigation measures have been identified for PhaHV-1 and -2. Further information and justification can be found in the *Treatment* and *Prevention and control* sections of the relevant literature review chapter. As PhaHV-1 and -2 have been detected in all free-ranging and captive populations of koalas tested to date, the options for preventing exposure to the virus in wild koalas may be limited. Note: Risk mitigation options are possibilities for risk mitigation and should not be confused with recommendations for action (which are listed below). Not all risk mitigation options will be currently available, feasible, universally applicable or cost-effective, but are listed here for completeness.

- Minimise concurrent infections, debilitation and other environmental stressors (e.g. predators, disturbance related to human activities) in individual koalas and populations, to minimise the likelihood of activation of latent PhaHV infections and any resultant disease (CCP2 and CCP14).
- Test koalas entering rehabilitation for herpesvirus and manage individuals while in care based on their herpesvirus status (CCP9).

5.12.6 Recommendations

General recommendations listed in *Section 1.6.2* apply to this disease hazard. Specific recommendations for this disease hazard have not been taken through a prioritisation exercise and are listed here in no particular order.

Hazard-specific recommendations

The following recommendations are specific to this hazard:

- Further investigate the biology and epidemiology of koala herpesviruses including expression of disease, the prevalence of PhaHV-1 and -2 in northern koala populations and relationship to other infections, co-morbidities and neoplasia.
- Develop additional diagnostic methods for herpesviruses.
- Develop nationally-agreed protocols for PhaHV testing of koalas in care.

5.12.7 References

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5.13 *Trypanosoma* spp. in Koalas – Risk Assessment

The literature review which supports this risk assessment is in *Appendix 5.13*.

5.13.1 Hazard summary

- Seven trypanosome species are known to infect koalas [1-5].
- The number of species and geographic distribution of trypanosome infections in koalas is likely to increase with further investigation [6].
- Most trypanosome species infecting koalas are present in other Australian species, including marsupials, bats and rodents [2, 4, 7-14].
- No Australian trypanosome species have been known to infect humans, although trypanosome species elsewhere are zoonotic [4, 7].
- Concurrent infection with as many as five trypanosome species has been reported in koalas [2, 4]
- The trypanosome life cycle generally involves an intermediate host vector [6]. The vectors of the trypanosomes parasitising koalas and other Australian wildlife are not known, but ticks are likely candidates [4, 9].
- Trypanosome infection has been commonly reported in koalas in NSW and Qld [2, 4, 5, 7-14] and studies have also detected trypanosomes in SA koalas [5]. Very few koalas have been tested elsewhere in Australia. Several of the trypanosome species known to infect koalas have been detected in other Australian mammals elsewhere in Australia (see *Appendix 5.13 Trypanosoma spp. - Literature Review*).
- The majority of wildlife trypanosomes are considered benign to their vertebrate hosts [7].
- Most koalas infected with trypanosomes are clinically healthy, but some associations with poor body condition, poor survival in rehabilitation, severe, strongly regenerative anaemia and neurological disorders have been observed.
- The ability of trypanosome infections to exacerbate immunosuppression in koalas or increase clinical severity of other infections (particularly *Chlamydia* and KoRV) is not known. Trypanosomes are known to compromise immunity in other species [7].
- Trypanosomes are diagnosed by identifying the parasites on blood smears, but more sensitive results can be obtained using molecular methods [1-4, 6, 10, 12, 15].
- There are no specific treatment recommendations for trypanosome infection in koalas.
- Prevention and control of trypanosome infections in general depend on breaking the cycle of transmission, which requires knowledge of competent vectors [16]. Reduction of stressors is likely to be important to limiting disease risks.
- For further detail on current knowledge of this hazard, refer to *Appendix 5.13 Trypanosoma spp. in Koalas - Literature Review*.

5.13.2 Justification for hazard selection

Trypanosome infections in koalas are commonly found in clinically normal koalas, but have also been associated with poor body condition, poor survival in rehabilitation, severe anaemia and neurological disease, and there is little understanding of the possible disease risks for koalas. Trypanosome infections in other species can cause severe disease.

5.13.3 Identified gaps in knowledge

- More research is needed to confirm the vectors and mode of transmission of trypanosomes in koalas, and in other Australian wildlife species [17, 18].
- The association between trypanosome presence in koalas and observable clinical signs consistent with trypanosomiasis is yet to be thoroughly investigated.
- Further investigation is needed to determine whether trypanosome polyparasitism affects the clinical impact of infection in koalas [4].
- The contribution of trypanosomes (both single and mixed infections) to clinical disease in koalas, particularly in the presence of co-infections such as *Chlamydia* and KoRV, has yet to be elucidated [4].

5.13.4 Risk assessment

Figure 17 shows a schematic of the hazard pathways and critical control points (CCPs) identified for this hazard. Critical control points are *key* points in the hazard pathway where risk mitigation methods could be most effective (see *Appendix 2.3 Risk Assessment Methods* for further information). Nineteen CCPs (CCP1-CCP19) were identified across all hazards, but only those applicable to this hazard are described below. See *Section 6 Critical Control Points by Disease Hazard* for a summary of CCPs across all hazards selected for detailed assessment.

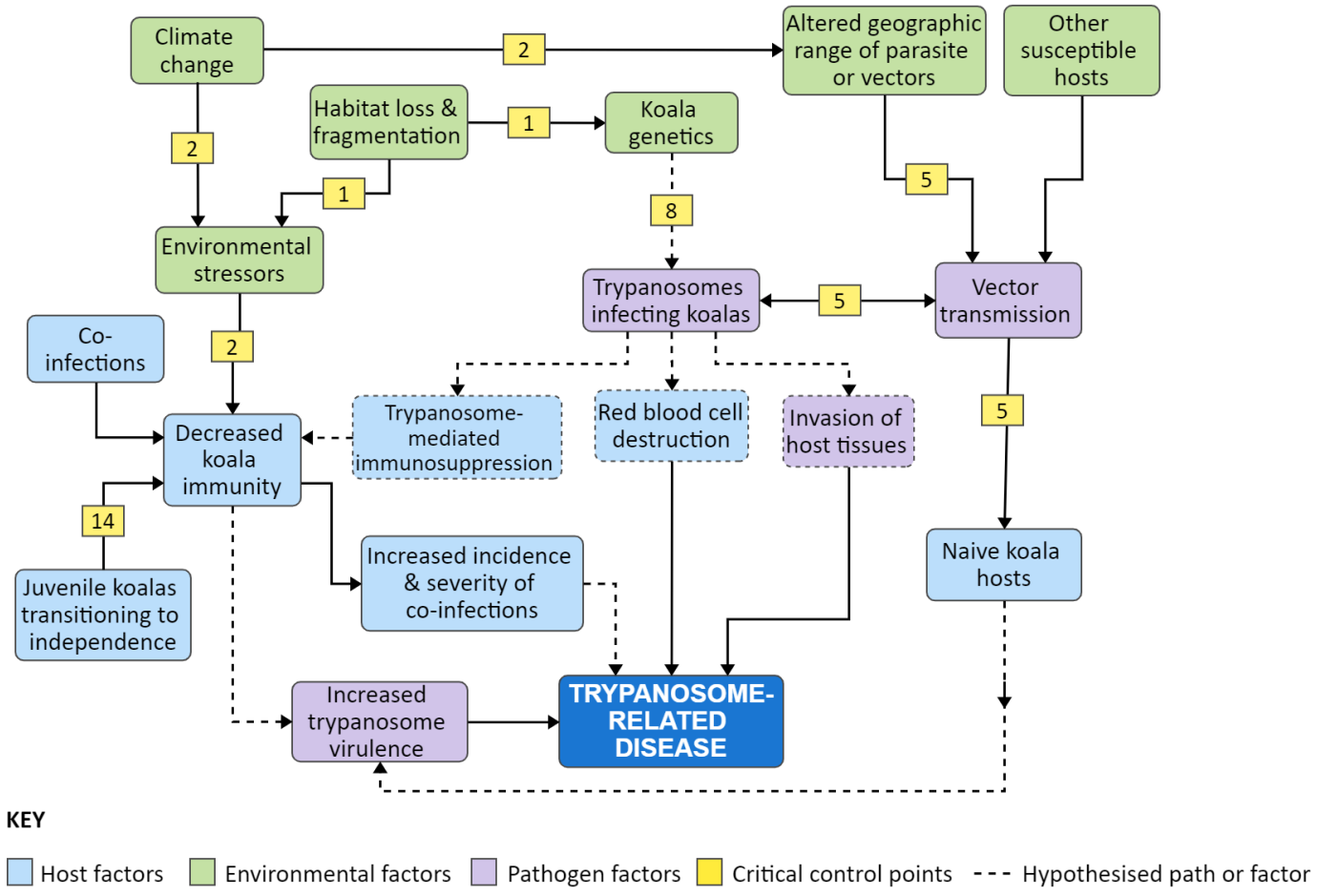

Figure 17 Hazard pathways and critical control points for trypanosome infection in koalas

Critical control points

CCP1 Habitat loss, fragmentation and reduction in quality

Habitat loss and reduction in habitat quality are major environmental stressors due to the koala's reliance on particular tree species for food, shelter and thermoregulation [19, 20]. Habitat fragmentation reduces connectivity between suitable koala habitats, forcing dispersal and potentially contributing to the loss of important genetic alleles in populations that can no longer interbreed [21-23]. Causes include urban expansion, land clearing for production, inappropriate fire management practices, the introduction of pests, weeds and plant pathogens, over-browsing by koalas as a result of local overcrowding, and the habitat-altering effects of climate change [24-30].

CCP2 Environmental stressors

Stressors in the koala's environment (in the wild or in captivity) contribute to general debilitation of the host, reduced immune function, and increased susceptibility to disease or severity of disease expression [20, 31-33]. Major environmental stressors for koalas include

habitat loss, fragmentation and reduction in quality; nutritional stress; climate change; extremes of weather and disturbance related to human activities [19, 34].

Environmental stressors may contribute to general debilitation and reduced immune function and may increase the likelihood of co-infections.

Trypanosome-related disease may be most likely to arise where immunosuppression occurs due to other stressors [35]. Changing climate may result in an increased or altered geographic range for trypanosomes or their vectors in Australia.

CCP5 Vectors

Some infectious diseases are transferred to the vertebrate host (in this case, the koala) by vectors. Koalas that are exposed to potential vectors (e.g. ticks, other invertebrates) may be at higher risk of infection with trypanosomes [13, 36].

CCP8 Genetics

The individual koala may have a genetic predisposition to the development of disease or increased severity of disease. Improving or at least maintaining genetic diversity in koala populations is likely to conserve adaptive potential [37] and encourage the retention of the most robust koala genetic profiles to avoid disease consequences of trypanosome infection.

CCP14 Concurrent infections and debilitation

Concurrent infections and debilitation can compromise immune function and general health in ways that increase the risk or severity of disease. The pathogenicity of an infectious hazard may be potentiated by co-infections.

Outside of Australia, infection with trypanosome species has been associated with severe, sometimes fatal, disease in the presence of co-infections [11]. It has been suggested that co-infection of *Trypanosoma* spp. with pathogens such as *Chlamydia* and KoRV may be associated with poor health and decreased survival of koalas [4].

Likelihood assessments

Trypanosomes are not transmitted directly between hosts [6] and there is no evidence that Australian trypanosomes are zoonotic [4, 7]. Therefore, the likelihood of entry and exposure for trypanosomes was considered only for koalas, and not for humans or other species.

Entry assessment

Trypanosomes have been reported in both northern and southern koalas. Most trypanosome species infecting koalas are present in other Australian mammals, including marsupials, bats and rodents [2, 4, 7-14] and have been detected in other parts of the koala's geographic range (see *Appendix 5.13 Trypanosoma spp. - Literature Review*).

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, the likelihood of trypanosomes entering, or being present, in a koala population is considered **HIGH**.

Exposure assessment

The prevalence of trypanosomes in koala populations is generally not known. Almost 74% of koalas in one Qld study were infected with at least one trypanosome species [11]. The means by which koalas acquire trypanosome infection is not known.

Based on the review of available information and using Table 7 in *Appendix 2.3 Risk Assessment Methods*, and applying the precautionary principle, the likelihood of exposure to trypanosomes for an individual koala is considered **HIGH**.

Using the principles of combining entry and exposure likelihood as outlined in *Appendix 2.3 Risk Assessment Methods*, the combined likelihood of entry and exposure for trypanosomes in koalas is considered **HIGH**.

Consequence assessments

Most koalas infected with trypanosomes are clinically healthy and the majority of wildlife trypanosomes are considered benign to their vertebrate hosts [1, 7, 11]. The presence of trypanosomes in koalas has been associated with poor body condition, poor survival in rehabilitation, severe anaemia and (in rare cases) neurological disease, but no causality has been shown [1, 11, 38].

Koala population resilience and viability

There are no data to show that the presence of trypanosomes in koalas has a population level effect. Most koalas with trypanosomes are considered clinically healthy and most trypanosomes in wildlife are considered benign.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of trypanosomes to koala population resilience and viability is considered **NEGLIGIBLE**.

Koala individual health and welfare

Most koalas infected with trypanosomes are clinically healthy and the disease states associated with trypanosome infection in koalas appear to be uncommon [1, 11, 38]. There are no data on the proportion of koalas infected with trypanosomes that display signs of ill health, but based on clinical reports, it is assumed to be very low.

Based on the review of available information and using Table 8 in *Appendix 2.3 Risk Assessment Methods*, the consequence of trypanosomes to koala individual health and welfare is considered **MINOR**.

Overall risk estimate

Since the consequence of trypanosome infection was evaluated as negligible for koala population resilience and viability, the estimate of risk for this hazard for koala populations was also considered **NEGLIGIBLE** (see *Appendix 2.3 Risk Assessment Methods*). Note, however that the level of confidence in this risk estimate (see below) is LOW.

The overall risk of trypanosomes to individual koala health and welfare, as defined using Table 9 in *Appendix 2.3 Risk Assessment Methods*, is **MODERATE**.

This assessment exceeds the acceptable risk thresholds as outlined in *Appendix 2.3 Risk Assessment Methods* for individual koalas, therefore risk management for trypanosomes is recommended.

However, the level of confidence in this assessment is LOW (see below) and there are significant gaps in knowledge concerning the impact of this parasite in koalas. It is recommended that this assessment be revised when new information becomes available.

Level of confidence in risk assessment

The level of confidence in the likelihood assessment is **LOW** as many koala populations have not been tested for trypanosomes and the method by which koalas acquire trypanosome infection is not known. The level of confidence in the consequence assessment is **LOW** as there is no clear understanding of the possible impacts of trypanosome infection on either individual koalas or populations. Therefore, the confidence in the risk estimate for trypanosomes is considered **LOW**.

5.13.5 Risk mitigation options

Few risk mitigation measures have been identified for trypanosomes. Further information and justification can be found in the *Treatment* and *Prevention and control* sections of the relevant literature review chapter. Note: Risk mitigation options are possibilities for risk mitigation and should not be confused with recommendations for action (which are listed below). Not all risk mitigation options will be currently available, feasible, universally applicable or cost-effective, but are listed here for completeness.

- Re-vegetation, restoration and preservation of habitat, including in urban landscapes (CCP1 and CCP8).
- Strengthen regulatory controls against habitat clearing and road development in koala habitat and dispersal corridors (CCP1 and CCP8).

These measures will reduce the impact of environmental stress on trypanosome disease expression and encourage the maintenance of larger wild koala populations, so that koalas have the most robust genetic profiles for avoiding disease consequences of trypanosome infections.

- Minimise concurrent infections, debilitation and other environmental stressors (e.g. predators, disturbance related to human activities) in individual koalas and populations, to reduce the risk of pathogenic consequences of trypanosome infections and co-infections (CCP2 and CCP14).
- Undertake vector control either on the animal or in the koala's environment, once vectors for trypanosomes infecting koalas are confirmed (CCP5).

- Support genetic diversity in koala populations to encourage the retention of the most robust koala genetic profiles for avoiding possible disease consequences of trypanosome infection (CCP8).

5.13.6 Recommendations

General recommendations listed in *Section 1.6.2* apply to this disease hazard. Specific recommendations for this disease hazard have not been taken through a prioritisation exercise and are listed here in no particular order.

Hazard-specific recommendations

The following recommendations are specific to this hazard:

- Clinically abnormal cases where trypanosomes are identified should receive a full work-up to identify associations with other causes of illness or mortality.
- Limiting exposure to vectors may be indicated for koalas in captivity and rehabilitation.

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6 Critical Control Points by Disease Hazard

Table 5 KDRA critical control points for disease hazards selected for detailed risk assessment

Coloured boxes marked with an "X" indicates the CCP applies to the disease hazard in question

For further details, see individual disease hazard risk assessments in *Section 5 Risk Assessments for Selected Hazards*.

CCP No.	CCP Description	Chlamydiosis	KoRV-related disease	Heat stress	Predator attack trauma	Thermal burn trauma	Cryptococcal disease	Motor vehicle trauma	Neoplasia	Sarcoptic mange	Oxalate nephrosis	Actinomycotic pneumonia	Herpesvirus-related disease	Trypanosome-related disease
1	Habitat loss, fragmentation & reduction in quality	x	x	x	x	x		x	x	x	x	x		x
2	Environmental stressors	x		x	x	x	x			x	x	x	x	x
3	Koala relocation	x	x				x		x					
4	Biosecurity practices	x								x				
5	Vectors													x
6	Diagnostics	x					x							
7	Disease reservoirs in other species									x				
8	Genetics	x	x	x					x	x	x	x		x
9	Naïve host	x	x						x	x			x	
10	Pathogen amplification						x							
11	Increased pathogen load	x	x				x							
12	Fire management practices			x		x					x			
13	Reduced water intake			x							x			
14	Co-infections & debilitation	x	x	x	x				x		x	x	x	x
15	Exposure to predators & severity of attack				x									
16	Exposure to roads							x						
17	Severity of trauma from vehicle impact							x						
18	Pathogen access to target tissue											x		
19	Emergency response to heightened risk			x		x								

7 Other Disease Hazards

7.1 Clinical Syndromes with Undefined or Multiple Aetiologies

The hazard refinement process (see *Appendix 2* for methodology) identified three disease hazards of koalas that did not lend themselves to the formal IUCN risk assessment process, because they lacked a clear single aetiology and case definition:

- wasting syndromes
- gut dysbiosis
- putative KoRV-associated disease syndromes.

These hazards are significant health issues for koalas, due to their impact on the rehabilitation process for koalas and the knowledge gaps in understanding of their impact. Their significance for koala health is summarised in this section.

7.1.1 Wasting syndromes

Terms such as “ill thrift” and “koala stress syndrome” are commonly used to describe the lethargy, depression and inappetence that characterise the sick koala [1-3]. With an improved understanding of predisposing mechanisms for these conditions, and in the context of this report, the term “wasting” is used to refer to debilitation associated with loss of appetite and body condition in koalas.

Koalas are susceptible to debilitating loss of body condition, because they have limited fat reserves and their eucalypt diet is intrinsically low in nutrients [4, 5]. Once koalas have lost body condition, it is difficult for them to regain it, and they may progress rapidly to severe emaciation and death [1, 6, 7].

Factors which can lead to wasting include:

- Nutritional stress caused by inadequate or poor quality habitat, where the availability of good quality nutrition is compromised [5, 8, 9].
- Dental attrition and disease which reduces digestive efficiency [10, 11].
- Sources of physiological stress such as water deprivation [12].
- Debilitation and other diseases that lead to inappetence [13].
- Long-term hospitalisation, frequent interventions and treatments [1].

Figure 18 shows a koala with signs of wasting. A diagram showing the contributing factors for wasting in koalas is provided in Figure 19.

Figure 18 A koala in rehabilitation showing signs of wasting (credit: Adelaide Koala and Wildlife Centre)

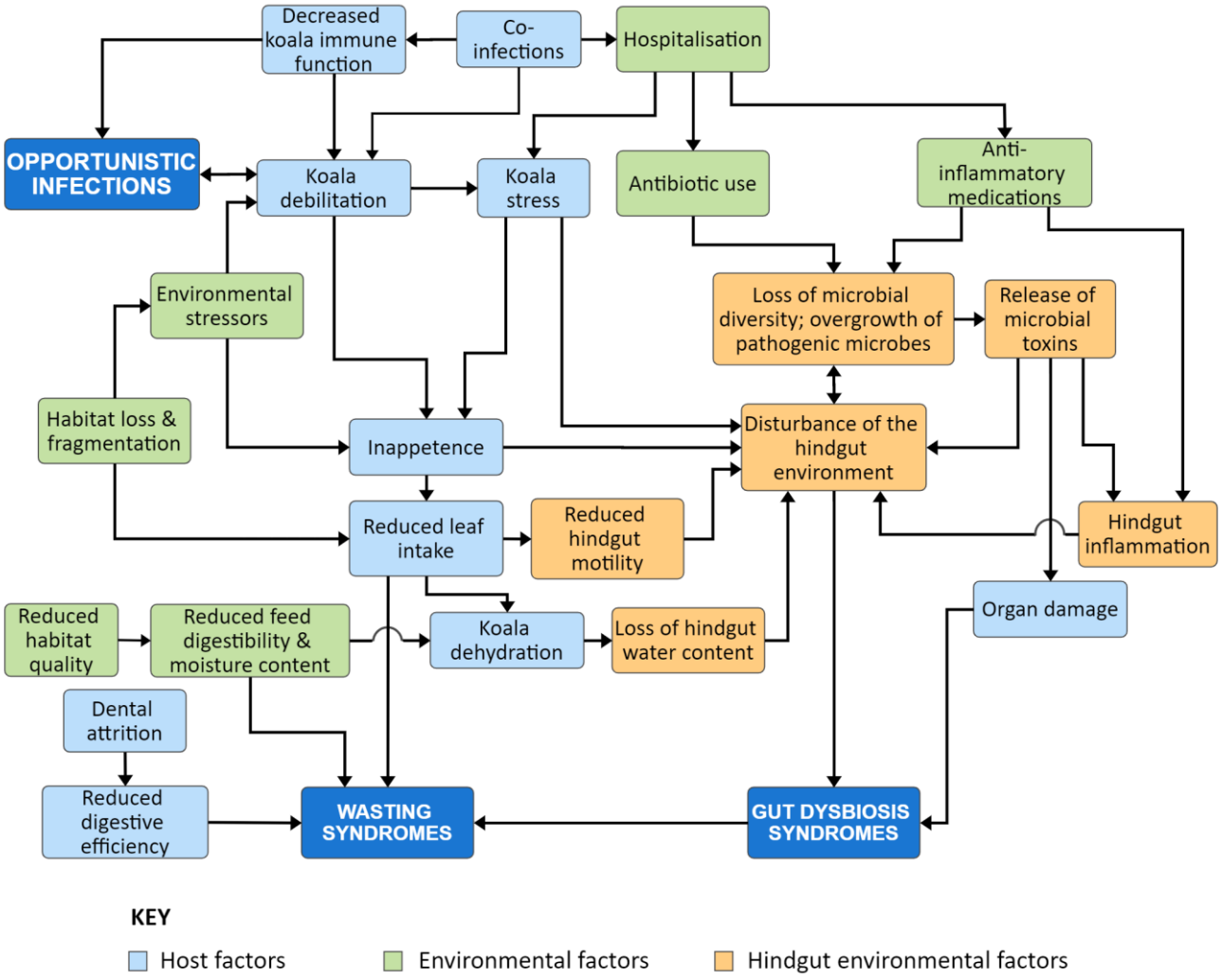

Figure 19 Key contributing factors for wasting syndromes, gut dysbiosis syndromes and opportunistic infections in koalas

Wasting syndromes may increase the severity of disease and have negative impacts on rehabilitation success. The likelihood of some non-infectious disease hazards (such as predator attack trauma) may be increased in koalas with wasting if their debilitation causes them to come to ground [6, 7]. Wasting is commonly associated with other infectious diseases hazards in koalas, although it is often difficult to determine whether loss of body condition is the cause or the effect of concurrent illness [7].

7.1.2 Gut dysbiosis syndromes

Koalas are hindgut fermenters, which means food is mostly digested by microbial fermentation in the large intestine and caecum [5]. The koala hindgut contains a diverse population of bacterial and fungal microbes that help to digest and detoxify the eucalypt diet [14, 15]. Circumstances that adversely affect the hindgut environment (e.g. changes in hindgut motility, water content, microbial number and diversity) disturb the balance and function of these microbes, leading to a spectrum of disorders collectively termed "caeco-colic dysbiosis and typhlocolitis syndrome" [16]. For the purposes of this report, these disorders are collectively referred to as "gut dysbiosis".

A range of factors can disturb the koala hindgut environment and lead to gut dysbiosis. Key factors include:

- Physiological stress, particularly stress associated with hospitalisation [16].
- Antibiotic medication, which can reduce hindgut microbial diversity and encourage the overgrowth of pathogenic microbes [17].
- Combining steroidal and non-steroidal anti-inflammatory medication, which may affect the function and health of the koala hindgut [16].
- Nutritional stress, such as reduced quality and hydration status of browse [18].
- Wasting, as hindgut environment and function are compromised when food intake is reduced [16].
- Dehydration [16].

Conditions arising from dysbiosis can range from mild disease (such as inappetence) and minor opportunistic microbial overgrowth (such as mild candidiasis) through to severe illness, such as hindgut ulceration, haemorrhage, perforation and severe loss of intestinal motility. Severe gut dysbiosis is commonly fatal in koalas [16].

Gut dysbiosis is a potential sequel for all conditions that cause stress and disease in koalas, particularly when these are associated with the use of antibiotics or prolonged captive care. Figure 19 shows the contributing factors for gut dysbiosis in koalas.

7.1.3 Putative KoRV-associated disease syndromes

Koala retrovirus (KoRV) poses risks to koala health through the effects of its insertion into the koala genome, which in broad terms leads to increased mutagenic and immunomodulatory effects (see *Appendix 5.2 Koala Retrovirus – Literature Review*). The link between mutagenic effects of KoRV and neoplasia is relatively well defined [19] and is

discussed in detail in the *Neoplasia – Literature Review*. The replication of KoRV in the koala's white blood cells is associated with a range of negative impacts on immune cell function [20, 21] which could manifest in a variety of ways, depending on factors such as the presence of co-infections and associated disease states.

Terms such as "koala immunodeficiency syndrome" ("KIDS") and "KoRV koala" have been coined in an attempt to summarise the wide range of signs associated with poor general health, high incidence of opportunistic infections and poor response to treatment which are presumptively attributed to immunodeficiency resulting from KoRV [22].

Clinicians and researcher have recognised the need to develop a clear case definition, based on clinical signs and laboratory testing, for KoRV-associated immunosuppressive disease syndromes. It has been suggested that it may be possible to identify a group of risk factors which are likely to indicate that KoRV is involved in the manifestation of disease. The identification of such risk factors may help to determine the role of KoRV in a clinical case [23].

The pathways leading to KoRV-associated disease are illustrated in *Section 5.2 Koala Retrovirus – Risk Assessment.*

7.2 Opportunistic Infections

Koalas are susceptible to opportunistic microbial infections that may occur when they become immunocompromised as a result of physiological stress, in the presence of immunosuppressive pathogens such as KoRV and herpesviruses, or which arise due to adverse environmental conditions. Figure 19 shows the contributing factors for opportunistic infections in koalas.

Opportunistic infections may cause health complications for individual koalas during rehabilitation. Multiple cases of opportunistic infections in a free-ranging population can have a disproportionate impact on small or fragmented free-ranging populations, as has been seen with *Chromobacterium violaceum* (see below) [24].

The risk mitigation options identified in the *Risk Assessment* chapters are likely to also be applicable for opportunistic infections. Examples of some opportunistic infections are given below.

7.2.1 Candidiasis

Candidiasis, caused by *Candida* fungal species (usually *C. albicans*) is a very common opportunistic infection of hospitalised and hand-reared koalas [13, 16]. Likely contributing factors include antibiotic use, poor hygiene, inappropriate diet, sudden diet transitions, gut dysbiosis, debilitation from concurrent disease, and physiological stress. The most common sites of candidiasis are the oral cavity and hindgut [16]. Candidiasis in koalas is amenable to treatment in the early stages, but advanced cases carry a poor prognosis, so early detection and vigilance are necessary in the captive and rehabilitation environments [16, 25].

7.2.2 Opportunistic bacterial infections

A range of bacteria have been reported to cause opportunistic infections among koalas in the wild, in captivity or in rehabilitation [13, 16, 24, 26]. Many of these have been associated with outbreaks of disease, some resulting in high morbidity and mortality. Cases are commonly associated with environmental stressors such as overcrowding, poor hygiene, cold or wet weather and co-infections. Examples include:

- *Bordetella bronchiseptica* causing pneumonia [27, 28].
- *Pseudomonas aeruginosa* causing multisystemic disease and mortality [29].
- *Salmonella* spp. causing septicaemia and sudden death [13, 25].
- *Chromobacterium violaceum* causing septicaemia (see below) [24].

Chromobacterium violaceum septicaemia

Heavy rainfall in summer and autumn of 2022 resulted in extensive flooding in northern NSW and south-east Qld [30]. Koala populations at Petrie and Coomera in south-east Qld were among many that experienced sustained heavy rainfall over several months. Both populations experienced acute mortalities during the flooding, resulting in the deaths of over 10% (n=13) of koalas in the Petrie population over a two week period and 5% (n=4) of the koalas in the Coomera population over approximately three months [31]. *Chromobacterium violaceum*, a water-borne bacterium, was identified as a cause of septicaemia and acute death in five of these cases [31]. These koala populations had retreated to low-lying riparian habitat due to the loss of more suitable habitat, and were probably in contact with wet conditions for a protracted period during the flooding [24]. Other water-borne pathogens (*Aeromonas* and *Plesiomonas* spp.) were also identified, but this was the first known identification of *C. violaceum* in koalas. Both populations were monitored (in the case of the Petrie population, for several years) and koalas were otherwise considered healthy and in good condition [24]. This example illustrates the vulnerability of fragmented koala populations to acute disease events and opportunistic infectious agents.

7.3 Recommendations

The following are recommendations for the management of the other disease hazards discussed in this section.

- Develop standardised, nationally-agreed terminology and case definitions for wasting syndrome, gut dysbiosis syndrome and putative KoRV-associated disease syndromes that are reviewed regularly as more information and knowledge comes to hand.
- Develop nationally-agreed guidelines for veterinarians and rehabilitators on the use of antibiotics in koalas that clearly summarise the risks and risk mitigation strategies.

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8 Key Knowledge Gap Summary

8.1 Koala Population Data

- More comprehensive and accurate data on the size and location of koala populations is required [1]. The assessment of disease impacts on populations is dependent on the quality of these data. The National Koala Monitoring Project (see *Section 2.6 Aligned Research Programs*) will be instrumental in addressing this knowledge gap.

8.2 Epidemiology

- The relative importance of disease (both generally and for specific disease hazards), among other threatening processes in koala populations, is incompletely understood and needs more investigation [1-5].
- Robust, longitudinal data sets on causes of morbidity and mortality in free-living koalas throughout their range are required. This will contribute to understanding of prevalence and population level impacts of various diseases. Compilation of data sets occurs in Qld and NSW at a state level [6, 7] but is lacking in Vic and SA.
- Basic epidemiological understanding is lacking for a number of infectious hazards in koalas. This includes KoRV, *Cryptococcus* spp., novel *Actinomyces* sp., phascolarctid herpesviruses, sarcoptic mange and *Trypanosoma* spp. Improved epidemiological knowledge for these disease hazards will enhance the level of certainty of risk assessments.
- Co-infections with KoRV, phascolarctid herpesviruses and trypanosomes are suspected, but not confirmed, to affect the severity of disease caused by other hazards. Further investigation of this, including an understanding of the mechanisms of causation and their degree of influence on disease state relative to other drivers is needed.

8.3 Genetics

- The role of koala genetics in disease susceptibility and expression is poorly understood for many disease hazards, particularly those demonstrating marked regional differences in clinical presentation and prevalence such as KoRV, *Chlamydia*, oxalate nephrosis and novel *Actinomyces* sp. (see *Section 5 Risk Assessments for Selected Hazards* for further information).

8.4 Koala Disease Management

- Nationally-agreed guidelines and protocols are required for many aspects of disease management in koalas, including diagnosis; triage, assessment and prognostic indicators; treatment and care; and record-keeping. Specific hazards with an identified need for such nationally-agreed guidelines and protocols include *Chlamydia*, heat stress, KoRV, motor vehicle trauma, predator attack trauma,

sarcoptic mange and thermal burns (see *Section 5 Risk Assessments for Selected Hazards* for further information).

- The short- and long-term outcomes of rehabilitation require ongoing evaluation and analysis to better inform decisions on triage, assessment and treatment, and assist in refinement of guidelines and protocols for disease hazards (see e.g. [8, 9]).
- Pharmacokinetic studies and clinical trials are required for therapeutic agents that may assist in the treatment of disease in koalas. Specific needs are identified in risk assessment chapters for *Chlamydia*, KoRV, cryptococcal disease, sarcoptic mange and oxalate nephrosis.
- Non-antimicrobial treatment options for disease prevention and control require exploration. In particular, there is a need for further work on vaccination options for KoRV and *Chlamydia*.

8.5 References

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9 Conclusions

The KDRA is the first disease risk analysis to examine disease risk for an Australian wildlife species at the national level. The nationwide approach was made possible with the enthusiastic participation and engagement of a range of stakeholders who each brought their unique perspective to evaluation of disease in this iconic species. The ongoing momentum of good will and collaboration between stakeholders will be an essential factor in implementing the recommendations of the KDRA and enabling the achievement of the shared vision for koala health and welfare.

The comprehensive, evidence-based threat analysis process clearly identified the links between disease and other drivers of koala endangerment. Through its recognition of the inter-relatedness of koala threats, the KDRA has identified the need for a more unified approach to koala conservation throughout Australia. The KDRA will be a resource for integration of koala health and disease actions into broader conservation efforts through ongoing alignment with other national initiatives.

The KDRA process has systematically identified multiple gaps in current scientific knowledge of koala disease. Further research should address these gaps, to enable further refinement of risk assessments and their level of confidence.

The prioritisation of recommendations for each hazard provides guidance for managers of koalas as they seek to optimise the effectiveness of disease risk mitigation efforts. Many risk management options identified through the KDRA have the capacity to mitigate multiple disease risks to koalas, particularly those that aim to preserve, increase and restore habitat and habitat connectivity. Good biosecurity practices will likewise be effective for many infectious hazards, and will always be more cost effective than eradication efforts.