Title

The invisible harm: land clearing is a significant issue of animal welfare

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Abstract

Land clearing is a significant environmental issue in Australia and an area of active legislative reform. Despite evidence of the harm that land clearing causes to individual animals, such harm is either ignored or considered only indirectly in environmental decision-making. We argue that the harm that land clearing causes to animals ought to be identified and evaluated in decision-making relating to land clearing and consider three propositions in support: (1) land clearing causes deaths that are physically painful and psychologically distressing because of their traumatic and debilitating nature; (2) pain, psychological distress, physical injuries and other pathological conditions arising from land clearing will occur over a prolonged period as animals attempt to survive in the cleared environment or in environments they are displaced to; and (3) based on current clearing rates, more than 50 million mammals, birds and reptiles are likely to be killed annually because of land clearing in Queensland and New South Wales. The scientific consensus about the harm caused by land clearing means that decisions to allow land clearing are decisions to allow most of the animals present to be killed and, as such, frameworks for decision-making ought to include proper evaluation of the harm to be imposed.

Additional keywords:

land clearing, animal welfare, harm, wildlife, mortality, morbidity, injury, stress, environmental decision-making

Introduction

Animal welfare is an increasingly significant component of environmental decision-making involving wildlife, whether the underlying decision relates to the conservation, exploitation or control of a species (Bradshaw and Bateson 2000; Twigg and Parker 2010; McMahon *et al*. 2012; Hampton *et al*. 2014; Descovich *et al*. 2015; Beausoleil *et al*. 2016). Factors that have influenced that shift in Australia include the evolution of animal welfare statutes in the Australian states and territories; government and non-government initiatives to communicate welfare issues (e.g. RSPCA Australia 2002; Cogger *et al*. 2003; Johnson *et al*. 2007; Commonwealth of Australia 2011; McLeod and Sharp 2014); and improvements in our understanding of how wild animals respond to non-lethal interactions with anthropogenic stressors (e.g. Bejder *et al*. 2009; Johnstone *et al*. 2012a; Brearley *et al*. 2013; van der Hoop *et al*. 2016; Tablado and Jenni 2017).

One consequence of this shift has been the development of objective and transparent procedures for the identification and assessment of the harms that human activities cause to individual animals, so that those harms can be appropriately weighed against the perceived benefits of the activity (Sharp and Saunders 2011; Calver 2012; Beausoleil *et al*. 2016). However, the integration of such harm-benefit frameworks into environmental decision-making has been uneven and it might fairly be said that we are currently better at identifying and evaluating certain harms than others. Further, there are some human activities for which no effective procedure exists for the identification and evaluation of harms caused to individual animals. The harm caused to native wildlife by land clearing is one example.

The basic premise of this article is that the deaths, physical injuries, other pathological conditions, pain and psychological distress experienced by individual wild animals during and after land clearing is a harm of sufficient intrinsic value that it ought to be identified and evaluated in decision-making, including in: assessments of applications for permits (or other authorisation) to clear native vegetation, assessments of planning or development proposals that will require land clearing, and strategic planning initiatives in which land clearing is contemplated (e.g. Department of the Premier and Cabinet 2015). Currently the harm that land clearing causes to the welfare of individual animals is either ignored in such decision-making or is considered only in instrumental terms, as when decision-makers focus solely upon the population-level effects of the loss of individuals that will result from a proposed clearing action.

To support this premise, we seek to demonstrate three basic propositions, namely that: (1) land clearing causes deaths that are physically painful and psychologically distressing because of their traumatic and debilitating nature; (2) animals will experience pain, psychological distress, physical injuries and other pathological conditions (i.e. morbidity) over a prolonged period as they attempt to survive in the harsh and unsuitable environment of the cleared area or in the environments they are displaced to; and (3) land clearing is likely to kill more than 50 million mammals, birds and reptiles in Queensland and New South Wales each year based on current clearing rates.

In advocating for greater consideration of the harm that land clearing causes to individual animals in environmental decision-making, we do not wish to minimise or disregard the tension that may arise between the objectives of conserving populations and species and those focused upon preventing harm to individual animals (Fulton and Ford 2001; White 2009; Paquet and Darimont 2010; Twigg and Parker 2010; Cooney *et al.* 2012; Jones *et al.* 2012; Lunney 2012a,b; Harrington *et al.* 2013). Rather, we seek here to set out a normative basis for why the harm that land clearing causes to individual animals ought to be considered as a relevant and significant harm in its own right.

The article uses terminology commonly applied in wildlife pathology and in wildlife forensic investigations (see Vogelnest and Woods 2008; Ladds 2009; Cooper 2013a,b; Vogelnest and Allan 2015, as well as materials supported by the Australian Registry of Wildlife Health at http://arwh.org/common-diseases). Definitions and relevant references for some terms are given in Table 1. Although the focus here is on harm to mammals, reptiles and birds, the issues are broadly applicable to other vertebrates (e.g. frogs: Hazell 2003) and to invertebrate species (Valentine 2004), though we note relevant differences across taxa in terms of (e.g.) the perception of pain and the experience of psychological distress (Koolhaas *et al*. 1999; Paul-Murphy *et al*. 2004; Wingfield 2005).

Land clearing in an Australia context

The conversion of native vegetation to other land uses, or 'land clearing', remains a fundamental pressure on the Australian environment (Jackson *et al.* 2016). Evans (2016) describes 'land clearing' as the 'local term for deforestation' in her analysis of the clearing and modification of native forest in Australia for agricultural, urban and industrial development. The amount of native vegetation that is cleared annually in Australia for those purposes is significant on global terms (Bradshaw 2012; Ritchie *et al.* 2013; Evans 2016). Systematic monitoring of clearing rates for native vegetation is undertaken in some jurisdictions. In Queensland, for example, the total state-wide woody vegetation clearing rate was reported to be 296 000 ha/year in 2014/15 (ie an area of approximately 54 km x 54 km), of which 91% was undertaken to convert land to pasture with the remaining 9% involving clearing for cropping, forestry, mining, infrastructure or settlement (Department of Science, Information

Technology and Innovation 2016). In New South Wales, a reduction in woody vegetation of 40 500 ha was reported for 2011–12 and 105 900 ha for 2012–13, with fire and forestry accounting for most of those losses (Office of Environment and Heritage 2016). The rates of woody vegetation loss due to clearing for cropping, pasture, infrastructure, and thinning in New South Wales were reported to be about 13 000 per year for 2011-2012 and 2012-2013 (Environment Protection Authority 2015; Office of Environment and Heritage 2016). The New South Wales figures are controversial, with suggestion that they may substantially under-estimate clearing rates in that state (Hannam 2016a,b).

Across Australia, the national State of the Environment report for 2016 reported the following total deforestation rates for the Australian states and territories for the period 2010-2014, based on deforestation data reproduced from Evans (2016): New South Wales (297 482 ha), Northern Territory (7 232 ha), Queensland (477 555 ha), South Australia (49 534 ha), Tasmania (17 163 ha), Victoria (54 941 ha), and Western Australia (119 231 ha) (Metcalfe and Bui 2016). Illegal native vegetation clearing also remain an issue in Australia (Bricknell 2010), with 'unexplained clearing' accounting for a significant proportion of total woody vegetation clearing detected by satellite monitoring in New South Wales (Office of Environment and Heritage 2014).

Regulatory frameworks for land clearing in Australia

Evans (2016,) describes New South Wales, Queensland, South Australia, Victoria and Western Australia as the 'historically high-deforestation states' in Australia. The regulatory frameworks for land clearing in those states typically consist of a complex amalgam of statutes, statutory instruments (e.g. regulations), policies, and guidance and technical materials (see COAG Standing Council on Environment and Water 2012; Evans 2016). Three observations may be made about the consideration that wild animal welfare receives within the regulatory frameworks for land clearing in those states.

First, the frameworks do not expressly recognise harm to the welfare of individual wild animals as a relevant category of harm. Those frameworks all identify particular harms that land clearing is said to cause, either as part of a list of statutory objects for the principal acts (e.g. section 3 of the New South Wales *Native Vegetation Act 2003* and section 3 of the Queensland *Vegetation Management Act 1999*) or as part of a list of principles said to guide decision-making about native vegetation clearance (e.g. schedule 5 of the Western Australian *Environmental Protection Act 1986*, schedule 1 of the South Australian *Native Vegetation Act 1991*, and clauses 52.16-6 and 52.17-5 of the Victoria Planning Provisions). The harms identified in those statutory objects and lists of principles include: loss of biodiversity, loss or fragmentation of habitat for native species, land degradation, salinity, deterioration of surface or underground water quality, and greenhouse gas emissions. Notably absent from the compendium of harms contained in those objects and principles is the harm that land clearing causes to the welfare of the animals using that vegetation. Similarly, considerations of animal welfare are not mentioned in *Australia's Native Vegetation Framework*, which was intended to provide a national policy framework to guide the ecologically sustainable management of Australia's native vegetation (COAG Standing Council on Environment and Water 2012).

Second, those regulatory frameworks do not require decision-makers to identify and evaluate the harm that a proposed clearing action may cause to the welfare of individual animals. None of the four principal acts indicated in the paragraph above nor the Victoria Planning Provisions contain any provision or clause that expressly require decision-makers to take animal welfare considerations (i.e. the causing of pain, physical injuries, other pathological conditions, and psychological distress to individual animals) into account when making a decision in relation to proposed clearing actions.

Three, some indirect consideration of harm to individual animals may occur if decision-makers are required to evaluate the potential impact of a proposed clearing action on a threatened species or to assess the value of vegetation proposed for clearing as habitat for that species. For example, threatened species assessment guidelines issued and enforced under s 94A of the New South Wales *Threatened Species Conservation Act 1995* provide for the evaluation of direct and indirect impacts of proposed developments, including land clearing, on individuals and their habitat (Department of Environment and Climate Change 2007). Nonetheless, the focus of those impact assessment guidelines, similar to guidelines in other Australian jurisdictions (e.g. Commonwealth of Australia 2013; Department of Environment and Heritage Protection, undated; Environmental Protection Authority 2016), is on population-level impacts. Further, as was observed by Thompson and Thompson (2015, page 223), ‘rarely, if ever, are impacts on the non-threatened fauna seriously considered in the [environmental impact] assessment process and mitigation strategies included in the approval conditions’.

For reasons of length it is not proposed here to set out any particular mechanisms by which the harm caused to animals could be integrated into decision-making for land-clearing. Nonetheless, it is relevant to point out that there are a range of potential statutory mechanisms, including: the express extension of statutory prohibitions on the taking of fauna to the circumstances of land clearing; the statutory expression of considerations or principles relating to animal welfare that decision-makers are required to consider in assessing applications to clear native vegetation; and statutory requirements for applicants or proponents to provide estimates of native fauna mortality likely to occur if a proposed clearing action proceeds.

Statutory changes could be complemented by the development of policy-based mechanisms, including assessment methodologies to appropriately identify and evaluate harms from land clearing actions. A key point is that the objective of making considerations of individual animal welfare legally relevant to decision-making about land clearing does not necessarily prescribe any particular mechanism by which that might be done.

Why the issue is relevant for wildlife researchers and managers and other environmental professionals

An evaluation of the harm that land clearing causes to wildlife may seem unnecessary as there would appear to be little scientific controversy as to the basic proposition that clearing native vegetation kills animals living at that site (Ehmann and Cogger 1985; Glanznig 1995; Williams *et al*. 2001; Cogger *et al*. 2003; McDonald *et al*. 2003; Department of the Environment 2006; Johnson *et al*. 2007). Nonetheless, there are several reasons why it is timely to review the harm that land clearing causes in a journal read by wildlife researchers and managers and environmental consultants, as well as by other environmental administrators and professionals.

First, regulation of the clearing of native vegetation remains an active area of legislative reform in Australia (Evans 2016). For example, in November 2016, following the release of a review of New South Wales biodiversity legislation in December 2014 (Byron *et al*. 2014) and a package of proposed biodiversity and land management reforms by the New South Wales Government in May 2016, the New South Wales Parliament passed the *Biodiversity Conservation Act 2016* and the *Local Land Services Amendment Act 2016*. Notably, those legislative reforms provided for the repeal of *Native Vegetation Act 2003* and the *Native Vegetation Regulation 2013* (as well as the *Threatened Species Conservation Act 1995*) and the introduction of a new statutory framework for native vegetation clearance in rural areas that will remove many existing controls on clearing activities. In Queensland, a bill to reform the *Vegetation Management Act 1999* failed to pass the Queensland Parliament following debate in August 2016. Those legislative reforms had been proposed as a response to increases in land clearing rates following the repeal or weakening of key statutory restrictions on land clearing in 2013 by the previous Queensland Government (Department of Science, Information Technology and Innovation 2016; Metcalfe and Bui 2016).

It is therefore worth emphasising that what the scientific community states, individually and collectively, about the harm that wild animals suffer because of land clearing can influence political debate about appropriate regulatory frameworks for land clearing. For example, on 17 August 2016, during the Second Reading speech in the Queensland Parliament for the *Vegetation Management (Reinstatement) And Other Legislation Amendment Bill 2016*, Jacklyn Trad (then Deputy Premier for the Queensland Government) observed:

> The fact is Queensland has a shameful history on the issue of broadscale tree clearing. In 1997 we were clearing over 400,000 hectares annually and, according to the Society for Conservation Biology Oceania's scientific declaration, it is estimated that 100 million native animals were dying each year between the years of 1997 and 1999 (Queensland Parliament 2016).

The text of that declaration – signed by over 250 scientists and environmental professionals – is available at http://scboceania.org/policystatements/landclearing/.

Second, it is axiomatic in conservation biology that local population declines and, ultimately, extinctions at regional- and species-level scales, are primarily driven by the mortality, morbidity and reduced reproductive success of individuals (e.g. Saunders *et al*. 1991; Ford *et al*. 2001; Lindenmayer and Fischer 2006; Ford 2011). There is therefore a basic commonality of interest between concerns about harm to individual animals and efforts focused upon conserving populations and species (Cogger *et al*. 2003; Johnson *et al*. 2007). On that basis, efforts to integrate consideration of the death, injury and other pathologies caused by land clearing into environmental decision-making should also support better conservation outcomes.

Third, on-going debate over the efficacy of offsets for land clearing (Gibbons and Lindenmayer 2007; Maron *et al*. 2015, 2016; May *et al*. 2016; Sonter *et al*. 2016) and of programs to capture and translocate animals from sites to be cleared (Germano *et al*. 2015; Thompson and Thompson 2015, 2016; Menkhorst *et al*. 2016) suggest a need for careful consideration of the precise harm that the removal of vegetation may cause to individual animals present at that site, so that such information can then assist in environmental decision-making. In particular, such information is necessary to support appropriate applications of the mitigation hierarchy, robust evaluations of potential offset measures for residual impacts, and adequate assessments of the overall significance and acceptability of impacts from land clearing.

Finally, the clearing of native vegetation for agricultural, urban and industrial development is clearly analogous to the practice of clearcutting in forestry, and thus investigation of wildlife responses to clearcutting may also yield insights for decision-makers assessing proposed land clearing actions (Semlitsch *et al*. 2009; Blumstein 2010). For example, studies of the behaviour and fate of individual animals after clearcutting have investigated whether observed declines in abundance reflect mortality associated with clearcutting, displacement into adjacent forest, or other processes (Tyndale-Briscoe and Smith 1969; Miller *et al*. 1997; Di Stefano *et al*. 2007; Semlitsch *et al*. 2008; Escobar *et al*. 2015).

Evaluating the harm that land clearing causes

The article deliberately uses the word 'harm' to describe the deaths, injuries and other pathological conditions (i.e. morbidity) that animals may suffer when vegetation is cleared for two reasons.

First, the term 'harm' carries with it connotations of physical injury and deliberate intent. While noting that individuals of some species may disperse to other habitats (if such habitat is available) when vegetation is cleared, the clear scientific consensus is that most, and in some cases all, of the individuals present at a site will die as a consequence of that vegetation being removed, either immediately or in a period of days to months afterwards (Cogger *et al*. 2003; McDonald *et al.* 2003; Johnson *et al*. 2007**)**.

That consequence is an important basic consideration for environmental decision-making because it means that any decision to clear native vegetation (or to allow it to be cleared) is also a decision to kill most or all of the individual animals inhabiting that vegetation (or to allow them to be killed). While a person who clears land may not desire for animals to suffer, suffering is the inevitable consequence of the decision to do so. The relevant question for decision-making is not *if* death, injury and other pathology will occur when land is cleared, but *how much* of that harm will occur, how severe it will be, and whether it ought to be avoided. If such harm is nonetheless deemed necessary, then the question is how the harm to be imposed could be minimised.

Broadly speaking, as a question of animal welfare, the removal of native vegetation may harm individual animals by causing some immediate or longer-term adverse change to their physical or mental state, either directly (e.g. by causing traumatic injury through the application of mechanical force during the clearing process) or indirectly, when animals interact with harmful physical and biological agents (e.g. inimical microclimates, absence of food, predators, aggressive conspecifics) present in the cleared environment itself or in the environment(s) the animal is displaced to. While efforts are sometimes made to distinguish between 'direct' and 'indirect' harms in environmental impact assessment (e.g. the New South Wales threatened species assessment guidelines differentiate between 'direct impacts' and 'indirect impacts': see Department of Environment and Climate Change 2007, pages 3-4), the physical of clearing native vegetation creates environments (or causes animals to encounter environments) where there is a high level of risk of exposure to harmful agents. Thus, land clearing can relevantly be said to place animals 'in harm's way' both during the clearing process and afterwards.

The Australian Animal Welfare Strategy, published in 2011, noted Australia's acceptance of the agreed international definition of animal welfare from the World Organisation for Animal Health (OIE) (Commonwealth of Australia 2011). That OIE definition appears at Article 7.1.1 in the current version of the OIE Terrestrial Animal Health Code (OIE 2016) and states, in part, that:

> Animal welfare means how an animal is coping with the conditions in which it lives. An animal is in a good state of welfare if (as indicated by scientific evidence) it is healthy, comfortable, well nourished, safe, able to express innate behaviour, and if it is not suffering from unpleasant states such as pain, fear, and distress.

The changes that land clearing causes to the physical or mental state of an animal can be considered in terms of the underlying pathology. Thus, land clearing could be said to 'harm' an animal if the clearing of vegetation causes (or leads to the development of) disease in that animal. Disease is here understood in the broad sense of being a departure from or an impairment of the normal structure or function of any part, organ or system of an animal which can be caused by (a) *infectious* agents (e.g. viruses, bacteria) and/or (b) *non-infectious* agents (e.g. physical injuries, nutritional deficiencies) (Wobeser 1981, 2006; Ladds 2009; Jakob-Hoff *et al.* 2014). Disease can vary in its degree of severity and may have multiple causes.

The second reason for using the word 'harm' is to establish a linkage between the harm caused by land clearing and the concept of harm to individual animals that underlies animal welfare legislation in Australia. Notably, several Australian animal welfare statutes include definitions for 'harm'. For example, section 3 of the South Australian *Animal Welfare Act 1985* (SA) defines 'harm' to mean any form of damage, pain, suffering or distress (including unconsciousness), whether arising from injury, disease or any other condition, while section 5 of the Western Australian *Animal Welfare Act 2002* (WA) defines 'harm' to include injury, pain, and distress evidenced by severe, abnormal physiological or behavioural reactions.

The purpose in noting those statutory definitions of 'harm' is not to suggest that land clearing is an animal cruelty offence under existing statutory frameworks for animal welfare in Australia, although arguably there may be grounds for a prosecution in some jurisdictions in circumstances where a clearing action is unlawful – on a basis that the suffering of animals was unnecessary because there was no legitimate object (i.e. purpose) for the activity, and where evidence to demonstrate the suffering of an animal is available (Radford 2000; McEwan 2016). Rather, we highlight the overlap in concepts of harm to demonstrate that land clearing causes harm that is of a character that would be prohibited if such harm were inflicted on an individual wild animal in other circumstances.

The concept of the harm that land clearing causes to animals should also be broad enough to include the adverse mental states (i.e. what we broadly refer to in this paper as psychological distress) that animals will experience as a consequence of experiencing pain, physical injury, debilitating pathological conditions, and the range of abiotic and biotic stressors they will encounter in environments fundamentally inimical to their survival. A conception of harm that includes mental states is consistent with the concepts of distress and wellbeing applied in the *Australian code for the care and use of animals for scientific purposes* (8th edition) (National Health and Medical Research Council 2013) and with conceptions of animal welfare used in frameworks for assessing the humaneness of wildlife management actions (Mellor *et al*. 2009; Sharp and Saunders 2011; Beausoleil *et al*. 2016).

We now turn to three specific propositions we propose in support of the view that the harm which land clearing causes to individual wild animals ought to be identified and evaluated in as a relevant harm in its own right in environmental decision-making.

Proposition 1: Land clearing causes deaths that are physically painful and psychologically distressing because of their traumatic and debilitating nature

Land clearing involves the removal of some or all of the above-ground biomass of native vegetation present at a site, as well as the destruction of burrows, middens and termitaria in or upon the substrate. The methods by which vegetation may be removed are diverse: e.g. plants may be cut, toppled, burnt, ploughed, grazed, ring-barked, poisoned, or otherwise damaged (Australian Greenhouse Office 2000; Seabrook *et al*. 2006). In most cases, vegetation is removed using machinery designed for earth-moving or forestry operations or, for broad-scale clearing, by dragging a chain between two tractors (Turnbull *et al.* 1992; Fulton and Majer 2006; Harris *et al*. 2010; Gleeson and Gleeson 2012; Thompson and Thompson 2015). Fallen vegetation is often pushed into piles of residue that are later removed, burnt, buried, wood-chipped, or allowed to decompose in place (Newell 1999; Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education 2013; Pyne 2015; Thompson and Thompson 2015).

The use of machinery to clear vegetation may cause traumatic injury or entrapment (i.e. physical confinement or burial within hollows, burrows or other cavities, underneath fallen stems or branches or other debris, or within soil or other matter) (Shine and Fitzgerald 1996; Rhind 1998, 2004; Cogger *et al*. 2003; Johnson *et al*. 2007; Andrews *et al*. 2008; Hanger and Nottidge 2009; Gleeson and Gleeson 2012; Thompson and Thompson 2015).

Possible outcomes include death arising from traumatic injury or non-drowning asphyxiation due to suffocation, as well as pain and shock. Forms of traumatic injuries that animals may experience as a result of land clearing include: compression injury, penetrating injury, laceration, degloving injury, amputation, fracture, joint luxation/subluxation, and blunt force injury to the skeleton, soft tissues, and central nervous system, and internal haemorrhage. Those injuries may be sustained through contact with vegetation (e.g. as it is felled or shifted after felling), soil, machinery, motor vehicles, or containment barriers.

Thompson and Thompson (2015) undertook a catch and relocation program for reptiles, amphibians and mammals during vegetation clearing at a coastal site in the Pilbara region of Western Australia and found that survivorship during clearing operations differed by the type of machinery used in clearing operations (e.g. dozer, excavator, loader) and by taxa. They observed that survivorship in the clearing process appeared to reflect the 'preferred retreat site' and movement speed of animals as well as the manner in which the vegetation was removed and the substrates disturbed.

Animals that live in tree hollows, either in living trees or in woody debris, may be injured, crushed, suffocated or entrapped when vegetation is felled and pushed into piles and substrates are disturbed (Rhind 1998, 2004; Hanger and Nottidge, 2009; Thompson and Thompson 2015). Clearing often involves the shifting of soil by machinery, which may capture, bury and crush animals present on the surface, in the soil or in termitaria (Thompson and Thompson 2015). Animals that shelter in debris piles may suffer burns or be incinerated when the piles are set alight or killed when the vegetation is transported, sawn or ground to woodchips.

The size of arboreal animals and the capacity for flight may affect whether they are killed or seriously injured when trees are felled. A study of the effects of logging on brush-tailed phascogales (*Phascogale tapoatafa*) in the Jarrah forest in southwestern Australia assessed the fate of phascogales and two possum species (western ringtail possums *Psuedocheirus occidentalis* and brushtail possums *Trichosurus vulpecula*) when trees were felled during logging operations (Rhind 1998, 2004). Rhind (2004) reported that three radio-collared phascogales who were present in trees when they were felled survived without apparent injury but that, of 65 possums found in the hollows of felled trees over an area of about 63 ha in a 12-week period, 17% had died when the tree was felled. Tyndale-Briscoe and Smith (1969) reported that the number of sugar gliders killed at tree fall was small and that most were able to escape the effect of impact by gliding free of the tree. Newell (1999) reported that Lumholtz's tree-kangaroos (*Dendrolagus lumholtzi*) remained in the tree or vine thicket they were using until a bulldozer approached the tree or a chainsaw had nearly toppled it, then leapt from the tree and quickly hopped away.

A draft code of practice developed for the welfare of animals affected by land clearing in Queensland includes descriptions of the deaths and injuries that animals may experience when land is cleared (Hanger and Nottidge 2009). The authors were then from the Australian Wildlife Hospital (now the Australia Zoo Wildlife Hospital) and could speak to the injuries suffered by animals because of land clearing through their own first-hand experience of them. The traumatic injuries and issues of entrapment that may arise when land is cleared were described in these terms:

> Animals injured directly in the process of vegetation clearing generally suffer from major crushing, deceleration or fall related injuries. Arboreal species may suffer from trauma associated with falling from a tree and/or crushing and avulsive injuries associated with boughs falling on or beside them. Such injuries include severe internal bleeding and organ disruption, multiple bone breaks, eye and head injuries. Animals resting in hollows, similarly, may receive crushing injuries if the hollow bough disintegrates, or suffer internal organ injuries and tearing as a result of rapid deceleration (deceleration injury).
>
> Ground dwelling animals, such as bandicoots, echidnas, snakes and lizards most commonly suffer from crushing and avulsive injuries (such as traumatic limb amputation), or may be buried alive during earthworks.
>
> Highly mobile species such as birds and macropods may avoid direct injury by machinery, but may suffer injuries by running into fences, motor vehicle strike or other misadventure.
>
> Injuries suffered by animals during land-clearing vary from mild to severe and fatal, but these animals are only rarely presented to wildlife hospitals or shelters. This is primarily because they are less likely to be discovered by members of the community and are more usually buried or confined in piles of debris during the process of clearing, which are then subsequently burnt or chipped (page 6).

We will deal further with the physical pain and psychological distress associated with debilitating conditions below, but it should be obvious that the types of traumatic injuries inflicted by land clearing cause tissue damage that will result in severe physical pain (see Bateson 1991; Weary *et al*. 2006). Animals will also experience the adverse mental states associated with the subjective experience of pain and with their cognitive assessment of their circumstances (including the experience of being smothered or physically entrapped) (Machin

2007; Mellor *et al.* 2009; Rogers 2010; Mosley 2011; Ferdowsian and Merskin 2012; Beausoleil *et al*. 2016; Miller and Patronek 2016; Griffin *et al*. 2017).

Proposition 2: Pain, psychological distress, physical injuries and other pathological conditions occur over a prolonged period as animals attempt to survive in the cleared environment or in other environments they are displaced to

Animals that survive the clearing process and who remain at the cleared site are left to inhabit a harsh and radically altered environment that is generally inimical to their survival (Tyndale-Briscole and Smith 1969; Newell 1999; Bladon *et al*. 2002; Cogger *et al.* 2003; Fulton and Majer 2006; Johnson *et al.* 2007; Thompson and Thompson 2015). Likewise, animals that leave the cleared site may encounter environments that are (e.g.) unfamiliar (Powell and Mitchell 2012), unsuitable (Sato *et al.* 2013), or hostile (Doherty *et al*. 2015).

Many native species show strong attachments to small areas of habitat and have relatively low mobility and thus, if vegetation is removed from a site, most individuals will not disperse to adjacent habitat (if such habitat is available), but will remain at or near the cleared site (Newell 1999; Cogger *et al.* 2003; Johnson *et al.* 2007; Kavanagh *et al*. 2007; Brown *et al.* 2008). Containment barriers around the area where clearing occurs may prevent those animals that do manage to avoid land clearing activity from actually being able to leave the cleared area (Environment and Communications References Committee 2017, paragraph 2.22).

Even if individuals are able to leave the cleared site, they are likely to die or to suffer physical injury or other pathological conditions because of the predators and other environmental challenges (including road strikes and other anthropogenic impacts) they will encounter, both in the environments they disperse through and in the habitat they are ultimately displaced to (Fischer and Lindenmayer 2000; Bennett 2003; Cogger *et al.* 2003; Johnson *et al.* 2007; Guy and Banks 2012; Armstrong *et al*. 2015; Menkhorst *et al*. 2016; Gonzalez-Astudillo *et al*. 2017). Further, a new habitat, if suitable, may already be occupied by conspecifics, which may lead to hostile interactions, competition for resources, and infectious disease transmission because of increased population density (Cogger *et al.* 2003; Wobeser 2006; Ladds 2009; Sainsbury and Vaughan-Higgins 2012; Pacioni *et al*. 2015). A new habitat may also result in contact with new species, who may act as either vectors for infectious disease or reservoirs for hitherto novel infectious diseases (Wobeser 2006). Even if dispersal is initially successful, the ultimate harm of dispersing to another habitat might not manifest until sometime later (McAlpine *et al*. 2017).

The clearing of vegetation from a site removes or substantially alters the habitat features present, including: the abiotic environmental conditions (e.g. temperature, humidity); the availability of resources (e.g. shelter/cover, food resources, water); and the biotic and social environment (e.g. the presence or absence and abundance of prey, predators, conspecifics, interspecific interactions with novel species including potential infectious disease vectors or reservoirs) (McIntyre and Hobbs 1999; Ford *et al*. 2001; McAlpine *et al*. 2002; Cogger *et al.* 2003; Kanowski *et al*. 2003; Wardell-Johnson *et al.* 2004; Pearson *et al.* 2005; Wobeser 2006; Johnson *et al.* 2007; Craig *et al*. 2012).

The range of harms that may occur as a consequence of those changes include but are not limited to: pain from tissue damage sustained through physical injury or other pathological conditions; predation; temperature-related injuries; stress-related pathology (e.g. adverse effects on reproduction, adversely affected immune function, suppression of growth);

secondary infection and shock/sepsis arising from injuries sustained during clearing or afterwards; maladaptation; misadventure; exertional myopathy; nutritional disease; infectious disease; dehydration; and increased likelihood of infectious disease transmission (see Table 1).

It is not feasible to discuss all of those harms here. However, the harms associated with stress-related pathologies deserve some comment as they are complex and are an area of active research for Australian species (Brearley *et al*. 2013; Bradshaw 2015; Narayan 2015; Hing *et al*. 2016; McAlpine *et al*. 2017). Notably, physiological stress responses to human-modified landscapes have been documented for several Australian marsupials (Brearley *et al*. 2012; Johnstone *et al*. 2012b; Davies *et al*. 2013; Hing *et al*. 2014; Narayan and Williams 2016).

An environment in which vegetation has recently been removed will present animals with multiple persistent and potentially interactive environmental stressors, both biotic (e.g. interactions with predators, food availability) and abiotic (e.g. suboptimal temperatures) (Wingfield 2005; Saunders *et al*. 2011; Sih *et al*. 2011; Schulte 2014; Hing *et al*. 2016; Narayan and Williams 2016; Schoepf *et al*. 2016). Where exposure to stressors is acute, an animal may mount a suite of behavioural and physiological responses in adaptation to the stressors (i.e. an allostatic response) and experience no lasting detriment to their health (McEwen 2005; Wobeser 2006; Schulte 2014). However, the intensity and duration of the stressors present in cleared environments are such that animals are likely to experience maladaptation and chronic stress (Moberg 2000; Gunderson *et al*. 2016; Narayan and Williams 2016). Further, they may sustain physical injuries which can act as an additional stressor (Ganswindt *et al*. 2010). In situations of maladaptation and chronic stress, the burden of maintaining adaptive responses to stressors may cause diversion of energy away from physiologic processes or have other deleterious health effects, and predispose the animal to disease (McEwen and Wingfield 2003;

McEwen 2005; Wobeser 2006; Hing *et al*. 2016). Notably, the immune function of an animal may be adversely affected after chronic physiological stress (Acevedo-Whitehouse and Duffus 2009; Brearley *et al*. 2013; Hing *et al*. 2016; Narayan and Williams 2016). Due to the energetic cost of mounting and maintaining an immune response, resource allocation away from such physiologic processes such as growth and reproduction may also result in minimised reproductive effort and adverse reproductive outcomes (Acevedo-Whitehouse and Duffus 2009).

Clearing-related mortality and morbidity in animals that survive the initial clearing process will typically reflect a multifactorial aetiology. For example, Gonzalez-Astudillo *et al*. (2017) analysed a substantial ($n = 20$ 250 entries) long-term (1997-2013) dataset of koala (*Phascolarctos cinereus*) records at wildlife hospitals in southeast Queensland to assess causes of morbidity and mortality. The authors identified 11 aetiologies, as well several spatial-temporal clusters (or 'hotspots') for the occurrence of particular aetiologies or for combinations of aetiologies. Gonzalez-Astudillo *et al*. (2017) suggested that these aetiologies were acting together as multifactorial determinants for koala decline in the region and observed that current extensive land clearing in Queensland 'could be leading to starvation in koalas, an issue that has surprisingly not generated much discussion' (page 7).

How long animals survive in cleared environments may reflect a range of factors, including: the species and condition of the individuals affected; the prevailing environmental conditions (e.g. summer vs. winter) and water availability; whether vegetation debris is left for a period after clearing; the proximity of other native vegetation; and the ability of predators to access the area (Newell 1999; Cogger *et al*. 2003; Sih *et al*. 2011; Schoepf *et al*. 2016). A study of the effects of habitat fragmentation on eastern pygmy-possums (*Cercartetus nanus*) found that a pre-clearing population of at least 15-20 individuals declined to 5-8 animals within 12 months after 30% of the study site was cleared (Bladon *et al*. 2002). The clearing coincided with the pygmy-possum breeding season and the recruitment of young appeared greatly reduced. Tyndale-Briscole and Smith (1969) found that, following clear-felling of a forest block, few sugar gliders dispersed into an adjacent depopulated area, indicating that most gliders died in situ without migrating out of their original home range. The authors reported that: 'The process of clear-felling thus results in the death of over 90% of the glider population inhabiting the area, only a few animals on the boundary being able to survive in adjacent forest. The majority lose weight, lose pouch young and presumably die within 1 week of tree fall' (page 656). Newell (1999) reported Lumholtz's tree-kangaroos surviving for months within clear-felled forest where debris was retained (prior to its eventual burning to create pasture), but that mortality rates of affected animals appeared to increase after clear-felling, with evidence of predation by domestic dogs or dingoes and also of infectious disease.

Animals who survive the clearing of vegetation but remain at the cleared site are likely to experience pain caused by physical injuries or by debilitating pathological conditions (e.g. malnourishment progressing to starvation, with negative energy balance also predisposing them to increased risk of infectious disease secondary to stress-induced immunosuppression) related to the clearing of vegetation, for periods ranging from days to months after clearing. These animals will also experience adverse mental states that persist (either continually or intermittently) for similar periods because of their: subjective experience of such pain; perception of other physiological states associated with pathological conditions such as thirst, hunger, nausea, dizziness, debility, and fatigue (Mellor *et al*. 2009); experience of fear or anxiety (or other adverse emotions) relating to the presence (or anticipation) of predators or hostile interactions with conspecifics or other species (Steimer 2002; Morgan and Tromborg

2007); and cognitive assessment of their circumstances and emotional state (Panksepp 2005; Mellor *et al*. 2009; Rogers 2010; Mellor 2016).

Proposition 3: Land clearing causes substantial mortality

The overall conclusions reached by Cogger *et al.* (2003) and Johnson *et al.* (2007) are strikingly clear – the removal of native vegetation leads to the rapid death of all or nearly all of the birds, reptiles, and mammals present. Cogger *et al.* (2003, page 14) stated that:

> One general assumption made in these calculations [of mortality from clearing], based primarily on knowledge of the ecology of a wide range of species, as well as the absence of any evidence that remaining remnant vegetation supports higher densities of a wide range of species following adjacent land clearing, is that the vast majority of animals displaced by clearing will die – either immediately or after a short space of time. Deaths result primarily from physical injury, exposure to lethal conditions of temperature or lowered microclimatic humidity, predation, or lack of food.

Both Cogger *et al.* (2003) and Johnson *et al.* (2007) estimated the scale of mortality from land clearing based on published population densities for birds, reptiles and mammals. These densities were then multiplied by available information on the area (in ha) of native vegetation cleared (in Queensland and New South Wales, respectively) to obtain estimates of mortality from clearing. Cogger *et al.* (2003) estimated that clearing in Queensland between 1997 and 1999 killed about 100 million native birds, mammals, and reptiles per year. Johnson *et al.* (2007) estimated that approved clearing in New South Wales between 1998 and 2005 killed more than 104 million native mammals, birds and reptiles. Both reports emphasised that the estimates were highly conservative and that actual mortality rates were likely to be substantially higher. Taylor and Dickman (2014) conducted a comparison of land clearing and mammal deaths in New South Wales from clearing before and after 2005, and suggested that a decline in clearing rates (and thus also in associated mammal deaths) post-2005 could be attributed to the more stringent clearing controls established by the New South Wales *Native Vegetation Act*

2003, which came into force in 2005. As indicated earlier, that Act is to be repealed as part of the legislative reforms undertaken by the New South Wales Government in 2016.

The 2006 State of the Environment report for Australia included an indicator (BD-08 Estimated loss of biodiversity resulting from land clearing) to represent the number of wild animals killed by land clearing (Department of the Environment 2006). The indicator was expressed as a measure of the pressure that land clearing places on biodiversity and was based on the assumption that:

> The immediate effect of clearance of native vegetation on plant and animal species can be significant. When land is cleared, everything that lives in it is killed. Estimates of the number killed are a direct indicator for this pressure.

The information presented in support of the indicator noted the mortality estimates in Cogger *et al*. (2003) and the absence of similar information on clearing-related mortalities on a continent-wide scale. The information provided for the indicator then stated, as a way of giving 'a very rough indicator, rather than a serious estimate', that:

> In the absence of any similar continent-wide study, if the Queensland averages were assumed to apply across Australia…a national death toll from land clearing can be extrapolated. AGO [Australian Greenhouse Office] remote sensing data suggests that around 424 727 hectares of wooded land was cleared across the continent in 2004…Using the WWF averages [a reference to information provided in Cogger *et al*. 2003], the animal death toll from this land clearing, in mammals, reptiles and birds alone, would have been around 95 million animals. Across the 17 million hectares cleared since 1972, approximately 4 billion birds, reptiles and mammals would have died.

Updated information for the indicator BD-08 did not appear in the 2011 or the 2016 State of the Environment reports. However, a rough assessment of the current situation can be undertaken by applying the methodology and fauna density estimates in Cogger *et al*. (2003) and Johnson *et al*. (2007) to the current estimates of clearing rates for (a) each biogeographic region in Queensland (Department of Science, Information Technology and Innovation 2016) and (b) the state of New South Wales as a whole (Office of Environment and Heritage 2016).

In Cogger *et al.* (2003) the overall annual clearing rate applied to estimate mortality in Queensland was 445 900 hectares per year, while Johnson *et al*. (2007) estimated mortality in New South Wales from 1998-2005 based on the amount of native vegetation approved for clearing by the state government across the whole 8-year period (639 930 ha). By comparison, the overall annual woody vegetation clearing rate for Queensland in 2014-15 was 296 000 ha/year (with forestry accounting for only 5% of that amount) (Department of Science, Information Technology and Innovation 2016), while the overall annual rate of woody vegetation loss for New South Wales in 2012-13 (for cropping, pasture, thinning and infrastructure only) was 13 000 ha. Those clearing rates would indicate, as a combined mortality estimate for the two states together, that more than 50 million mammals, birds and reptiles are killed each year in Queensland and NSW because of land clearing.

Conclusion

Free-ranging native animals suffer, of course, independent of any human action, and that suffering is both severe and substantial (Kirkwood, 1994; Nussbaum, 2006; Doherty *et al.* 2016). A world of more frequent and more intense wildfires also promises that animals will suffer, both during fires and in their aftermath (Chia *et al.* 2015), as does a world of more roads and more traffic (Lunney 2013; Rhodes *et al*. 2014).

However, the central fact remains that land clearing causes death, physical injury and other pathological conditions to animals in a manner that is: direct (i.e. the clearing of vegetation either causes damaging physical contact with animals or creates the cleared environment that animals subsequently experience); demonstrable (i.e. the harms can be demonstrated through forensic or scientific investigation); and capable of being avoided or minimised with appropriate application of the mitigation hierarchy.

Thus, efforts to ignore the harm caused by land clearing must present as an act of wilful blindness which is inconsistent with objective and transparent decision-making about the benefits and harms of land clearing. Further work is needed to develop appropriate statutory and policy-based mechanisms to identify and evaluate the harms caused by proposed land clearing activities and to allow for the effective consideration of those harms in decision-making relating to land clearing.

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References

Acevedo-Whitehouse, K., and Duffus, A. L. J. (2009). Effects of environmental change on wildlife health. *Philosophical Transactions of the Royal Society B* **364**, 3429-3438. doi: 10.1098/rstb.2009.0128

Andrews, K. M., Gibbons, J. W., Jochimsen, D. M., and Mitchell, J. (2008). Ecological effects of roads on amphibians and reptiles: a literature review. *Herpetological Conservation*, **3**, 121-143.

Armstrong, D., Hayward, M., Moro, D., and Seddon, P. (Eds.) (2015). 'Advances in reintroduction biology of Australian and New Zealand fauna.' (CSIRO Publishing: Clayton South, Victoria.)

Australian Greenhouse Office. (2000). Land clearing: a social history. National Carbon Accounting System Technical Report No. 4. (Commonwealth of Australia: Canberra.)

Bateson, P. (1991). Assessment of pain in animals. *Animal Behaviour* **42**, 827-839.

Beausoleil, N. J., Fisher, P., Littin, K. E., Warburton., B., Mellor, D. J., Dalefield, R. R., and Cowan, P. (2016). A systematic approach to evaluating and ranking the relative animal welfare impacts of wildlife control methods: poisons used for lethal control of brushtail possums (*Trichosurus vulpecula*) in New Zealand. *Wildlife Research* **43**, 553-565. doi: 10.1071/WR16041

Bejder, L., Samuels, A., Whitehead, H., Finn, H., and Allen, S. (2009). Impact assessment research: use and misuse of habituation, sensitisation and tolerance to describe wildlife responses to anthropogenic stimuli. *Marine Ecology Progress Series* **395**, 177-185. doi: 10.3354/meps07979

Bennett, A. F. (2003). Linkages in the landscape: the role of corridors and connectivity in wildlife conservation. Second edition. (IUCN: Gland, Switzerland and Cambridge, UK.)

Bladon, R. V., Dickman, C. R., and Hume, I. D. (2002). Effects of habitat fragmentation on the demography, movements and social organisation of the eastern pygmy-possum (*Cercartetus nanus*) in northern New South Wales. *Wildlife Research* **29**, 105-116.

Blumstein, D. T. (2010). Conservation and animal welfare issues arising from forestry practices. *Animal Welfare* **19**, 151-157.

Bradshaw, E. L., and Bateson, P. (2000). Animal welfare and wildlife conservation. In 'Behaviour and Conservation'. (Ed. L. M. Gosling and W. J. Sutherland). pp. 330-348. (Cambridge University Press: Cambridge.)

Bradshaw, C. J. A. (2012). Little left to lose: deforestation and forest degradation in Australia since European colonization. *Journal of Plant Ecology* **5**, 109-120. doi: 10.1093/jpe/rtr038

Bradshaw, S. D. (2015). A state of non-specific tension in living matter? Stress in Australian animals. *General and Comparative Endocrinology* (in press, available online). doi: 10.1016/j.ygcen.2015.10.002

Brearley, G., McAlpine, C., Bell, S., and Bradley, A. (2012). Influence of urban edges on stress in an arboreal mammal: a case study of squirrel gliders in southeast Queensland, Australia. *Landscape Ecology* **27**, 1407-1419. doi: 10.1007/s10980-012-9790-8

Brearley, G., Rhodes, J., Bradley, A., Baxter, G., Seabrook, L., Lunney, D., Liu, Y., and McAlpine, C. (2013). Wildlife disease prevalence in human-modified landscapes. *Biological Reviews of the Cambridge Philosophical Society* **88**, 427-442. doi: 10.1111/brv.12009

Bricknell, S. (2010). Environmental crime in Australia. (Australian Institute of Criminology: Canberra.)

Brown, G. W., Bennett, A. F., and Potts, J. M. (2008). Regional faunal decline - reptile occurrence in fragmented rural landscapes of south-eastern Australia. *Wildlife Research* **35**, 8-18.

Byron, N., Craik, W., Keniry, J. and Possingham, H. (2014). A review of biodiversity legislation in NSW: final report. Prepared by the Independent Biodiversity Legislation Review Panel. (State of NSW and the NSW Office of Environment and Heritage). Available at http://www.environment.nsw.gov.au/resources/biodiversity/BiodivLawReview.pdf [Accessed: 24 January 2017].

Calver, M. (2012). Animal trapping and animal welfare. In 'Proceedings of the 2012 ANZCCART Conference'. (Ed. G. Dandie.) pp. 65-82. (Australian and New Zealand Council for the Care of Animals in Research and Teaching Ltd.)

Chia, E. K., Bassett, M., Nimmo, D. G., Leonard, S. W. J., Ritchie, E. G., Clarke, M. F., and Bennett, A. F. (2015). Fire severity and fire-induced landscape heterogeneity affect arboreal mammals in fire-prone forests. *Ecosphere* **6**,190.

COAG Standing Council on Environment and Water. (2012). Australia's native vegetation framework. (Australian Government, Department of Sustainability, Environment, Water, Population and Communities: Canberra.)

Cogger, H., Ford, H., Johnson, C., Holman, J., and Butler, D. (2003). 'Impacts of land clearing on Australian wildlife in Queensland.' (WWF Australia: Brisbane.)

Commonwealth of Australia. (2011). Australian animal welfare strategy and national implementation plan 2010-2014. (Commonwealth of Australia: Canberra.) Available at http://www.australiananimalwelfare.com.au/content/about-aaws [Accessed: 24 January 2017].

Commonwealth of Australia. (2013). Significant impact guidelines 1.1 - Matters of National Environmental Significance. *Environment Protection and Biodiversity Conservation Act 1999*.

(Department of the Environment, Water, Heritage and the Arts: Sydney.) Available at http://www.environment.gov.au/epbc/publications [Accessed 21 April 2017]

Cooney, R., Archer, M., Baumber, A., Ampt, P., Wilson, G., Smits, J., and Webb, G. (2012). THINKK again: getting the facts straight on kangaroo harvesting and conservation. In ‘Science Under Siege: Zoology Under Threat’. (Eds. P. Banks, D. Lunney, and C. Dickman.) pp. 151-160. (Royal Zoological Society of New South Wales, Mosman.) doi: 10.7882/FS.2012.040

Cooper, J. E. (2013a). Working with live animals. In ‘Wildlife Forensic Investigation: Principles and Practice’. (Eds. J. E. Cooper, and M. E. Cooper.) pp. 181-236. (CRC Press: Boca Raton, Florida.)

Cooper, J. E. (2013b). Working with dead animals. In ‘Wildlife Forensic Investigation: Principles and Practice’. (Eds. J. E. Cooper, and M. E. Cooper.) pp. 237-323. (CRC Press: Boca Raton, Florida.)

Cooper, J. E., and Cooper, M. E. (2013). Glossary. In ‘Wildlife Forensic Investigation: Principles and Practice’. (Eds. J. E. Cooper, and M. E. Cooper.) pp. 507-520. (CRC Press: Boca Raton, Florida.)

Craig, M. D., Hardy, G. E. S. J., Fontaine, J. B., Garkakalis, M. J., Grigg, A. H., Grant, C. D., Fleming, P. A., and Hobbs, R. J. (2012). Identifying unidirectional and dynamic habitat filters to faunal recolonisation in restored mine-pits. *Journal of Applied Ecology* **49,** 919–928. doi:10.1111/j.1365-2664.2012.02152.x

Davies, N. A., Gramotnev, G., McAlpine, C., Seabrook, L., Baxter, G., Lunney, D., Rhodes, J. R., and Bradley, A. (2013). Physiological stress in koala populations near the arid edge of their distribution. *PLoS One* **8**, e79136. doi:10.1371/journal.pone.0079136

Department for Sustainability, Environment, Water, Population and Communities. (2011). State of the Environment 2011: an independent report presented to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities. Chapter 5.3.2.2. (Department for Sustainability, Environment, Water, Population and Communities: Canberra.) Available at http://www.environment.gov.au/science/soe [Accessed: 24 January 2017].

Department of Environment and Climate Change. (2007). Threatened species assessment guidelines: the assessment of significance. (Department of Environment and Climate Change: Sydney.) Available at http://www.environment.nsw.gov.au/resources/threatenedspecies/tsaguide07393.pdf [Accessed: 20 April 2017]

Department of Environment and Heritage Protection. (undated). Environmental impact statement information guideline - flora and fauna. (Department of Environment and Heritage Protection.) Available at https://www.ehp.qld.gov.au/management/impact-assessment/eis-processes/eis-tor-support-guidelines.html [Accessed: 21 April 2017]

Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education. (2013). Australian national greenhouse accounts: Australian land use, land use change and forestry emissions projections to 2030. (Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education: Canberra.) Available at https://www.environment.gov.au/climate-change/publications/australian-land-use-land-use-change-and-forestry-emissions-projections-2030 [Accessed: 24 January 2017].

Department of the Premier and Cabinet. (2015). Perth and Peel Green Growth Plan for 3.5 million: Draft Strategic Conservation Plan for the Perth and Peel Regions. (Department of the Premier and Cabinet: Perth.) Available at https://www.dpc.wa.gov.au/Consultation/StrategicAssessment/Pages/Draft-Green-Growth-Plan-documents.aspx [Accessed: 28 April 2017].

Department of Science, Information Technology and Innovation. (2016). Land cover change in Queensland 2014–15: a statewide landcover and trees study (SLATS) report. (Department of Science, Information Technology and Innovation: Brisbane.) Available at https://www.qld.gov.au/environment/land/vegetation/mapping/slats-reports/ [Accessed: 24 January 2017].

Department of the Environment. (2006). State of the Environment 2006 - Indicator: BD-08 Estimated loss of biodiversity resulting from land clearing. (Department of the Environment: Canberra.) Available at http://www.environment.gov.au/node/22134 [Accessed: 24 January 2017].

Descovich, K. A., McDonald, I. J., Tribe, A., and Phillips, C. J. C. (2015). A welfare assessment of methods used for harvesting, hunting and population control of kangaroos and wallabies. *Animal Welfare* **24**, 255-265. doi:10.7120/09627286.24.3.255

Di Stefano, J., Anson, J. A., York, A., Greenfield, A., Coulson, G., Berman, A., and Bladen, M. (2007). Interactions between timber harvesting and swamp wallabies (Wallabia bicolor): space use, density and browsing impact. *Forest Ecology and Management* **253**, 128-137.

Doherty, T. S., Dickman, C. R., Nimmo, D. G., and Ritchie, E. G. (2015). Multiple threats, or multiplying the threats? Interactions between invasive predators and other ecological disturbances. *Biological Conservation* **190**, 60-68. doi:10.1016/j.biocon.2015.05.013

Doherty, T. S., Dickman, C. R., Johnson, C. N., Legge, S. M., Ritchie, E. G., and Woinarski, J. C. Z. (2016). Impacts and management of feral cats *Felis catus* in Australia. *Mammal Review* (published online). doi:10.1111/mam.12080

Ehmann, H. F. W. and Cogger, H. G. (1985). Australia's endangered herpetofauna: a review of criteria and policies. In 'The Biology of Australasian Frogs and Reptiles'. (Eds. G. C. Grigg, R. Shine and H. F. W. Ehmann.) pp. 435-447 in (Surrey Beatty and Sons with Royal Zoological Society of New South Wales: Sydney.)

In 'Wildlife Forensic Investigation: Principles and Practice'. (Eds. J. E. Cooper, and M. E. Cooper.) pp. 181-236. (CRC Press: Boca Raton, Florida.)

Environment and Communications References Committee. Continuation of construction of the Perth Freight Link in the face of significant environmental breaches. Report of the Senate Environment and Communications References Committee. (Senate Printing Unit: Parliament Canberra.) Available at http://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/PerthFreight/Report [Accessed: 22 April 2017]

Environmental Protection Authority. (2016). Technical guidance - terrestrial fauna surveys. (Environmental Protection Authority: Perth.) Available at http://www.epa.wa.gov.au/policies-/technical-guidance-terrestrial-fauna-surveys [Accessed: 21 April 2017]

Escobar, M. A. H., Uribe, S. V., Chiappe, R., Estades, C. F. (2015). Effect of clearcutting operations on the survival rate of a small mammal. *PLoS ONE* 10(3): e0118883. doi:10.1371/journal.pone.0118883

Evans, M. C. (2016). Deforestation in Australia: drivers, trends and policy responses. *Pacific Conservation Biology* **22**, 130-150. doi: 10.1071/PC15052

Ferdowsian, H., Merskin, D. (2012). Parallels in sources of trauma, pain, distress, and suffering in humans and nonhuman animals. *Journal of Trauma and Dissociation* **13**, 448-468. doi: 10.1080/15299732.2011.652346

Fischer, J., and Lindenmayer, D. B. (2000). An assessment of the published results of animal relocations. *Biological Conservation* **96**, 1-11.

Ford, H. A., Barrett, G. W., Saunders, D. A., and Recher, H. F. (2001). Why have birds in the woodlands of southern Australia declined? *Biological Conservation* **97**, 71-88. doi:10.1016/S0006-3207(00)00101-4

Ford, H.A. (2011). The causes of decline of birds of eucalypt woodlands: advances in our knowledge over the last 10 years. *Emu* **111**, 1-9. doi: 10.1071/MU09115

Fulton, G. R., and Ford, H. A. (2001). The conflict between animal welfare and conservation. *Pacific Conservation Biology* **7**, 152-160.

Fulton, G. R., and Majer, J. D. (2006). The effect of recent chaining on birds in the eastern wheatbelt of Western Australia. *Pacific Conservation Biology* **12**, 168-174.

Ganswindt, A., Münscher, S., Henley, M., Palme, R., Thompson, P., and Bertschinger, H. (2010). Concentrations of faecal glucocorticoid metabolites in physically injured free-ranging African elephants *Loxodonta africana*. *Wildlife Biology* **16**, 323-332. doi: 10.2981/09-081

Germano, J. M., Field, K. J., Griffiths, R. A., Clulow, S., Foster, J., Harding, G., and Swaisgood, R. R. (2015). Mitigation-driven translocations: are we moving wildlife in the right direction? *Frontiers in Ecology and the Environment* **13**, 100-105. doi: 10.1890/140137

Gibbons, P., and Lindenmayer, D. B. (2007). Offsets for land clearing: no net loss or the tail wagging the dog? *Ecological Management and Restoration* **8,** 26-31. doi:10.1111/j.1442-8903.2007.00328.x

Glanznig, A. (1995). Native vegetation clearance, habitat loss and biodiversity decline. An overview of recent native vegetation clearance in Australia and its implications for biodiversity. Biodiversity Series Paper No. 6. (Department of the Environment, Sport and Territories: Canberra.) Available at http://www.environment.gov.au/archive/biodiversity/publications/series/paper6/ [Accessed: 28 April 2017].

Gleeson, J., and Gleeson, D. (2012). 'Reducing the Impacts of Development on Wildlife.' (CSIRO Publishing: Melbourne.)

Gonzalez-Astudillo, V., Allavena, R., McKinnon, A., Larkin, R., and Henning, J. (2017). Decline causes of Koalas in South East Queensland, Australia: a 17-year retrospective study of mortality and morbidity. *Scientific Reports* **7**, 42587. doi: 10.1038/srep42587

Griffin, A. S., Tebbich, S. and Bugnyar, T. (2017). Animal cognition in a human-dominated world. *Animal Cognition* **20**, 1-6. doi:10.1007/s10071-016-1051-9

Gunderson, A. R., Armstrong, E. J., and Stillman, J. H. (2016). Multiple stressors in a changing world: the need for an improved perspective on physiological responses to the dynamic marine environment. *Annual Review of Marine Science* **8**, 357-378.

Guy, A. J., and Banks, P. (2012). A survey of current rehabilitation practices for native mammals in eastern Australia. *Australian Mammalogy* **34**, 108-118. doi: 10.1071/AM10046

Hampton, J. O., Cowled, B. D., Perry, A. L., Miller, C. J., Jones, B., and Hart, Q. (2014). A quantitative analysis of animal welfare outcomes in helicopter shooting: a case study with feral dromedary camels (*Camelus dromedarius*). *Wildlife Research* **41**, 127-145. doi:10.1071/WR13216

Hanger, J. and Nottidge, B. (2009). Draft Queensland code of practice for the welfare of wild animals affected by land-clearing and other habitat impacts and wildlife spotter catchers. (Australia Zoo Wildlife Hospital: Beerwah, Queensland.) Available at http://www.aph.gov.au/DocumentStore.ashx?id=42991366-5939-4305-90be-c56e3365947e [Accessed: 24 January 2017].

Hannam, P. (2016a). '"Bombshell": Just one-sixth of rural land-clearing tracked in NSW, ANU's Philip Gibbons says.' *The Sydney Morning Herald*, published online: 3 May 2016. Available at http://www.smh.com.au/environment/conservation/bombshell-just-onesixth-of-rural-landclearing-tracked-in-nsw-anus-philip-gibbons-says-20160502-gojvkw.html [Accessed: 24 January 2017].

Hannam, P. (2016b). 'Land clearing in NSW accelerates with almost two-thirds of it "unexplained".' *The Sydney Morning Herald*, published online: 4 August 2016. Available at http://www.smh.com.au/environment/conservation/land-clearing-in-nsw-accelerates-with-almost-twothirds-of-it-unexplained-20160803-gqk052.html [Accessed: 24 January 2017].

Harrington, L. A., Moehrenschlager, A., Gelling, M., Atkinson, R. P., Hughes, J., and Macdonald, D. W. (2013). Conflicting and complementary ethics of animal welfare considerations in reintroductions. *Conservation Biology* **27**, 486-500. doi: 10.1111/cobi.12021

Harris, R. J., Mioduszewski, P., and Molony, L. N. (2010). Vegetation responses to chaining in an isolated remnant in Western Australia's wheatbelt. *Journal of the Royal Society of Western Australia* **93**, 1-11.

Hazell, D. (2003). Frog ecology in modified Australian landscapes: a review. *Wildlife Research* **30**, 193-205.

Hing, S., Narayan, E., Thompson, R. A., and Godfrey, S. (2014). A review of factors influencing the stress response in Australian marsupials. *Conservation Physiology* **2**, cou027. doi: 10.1093/conphys/cou027

Hing, S., Narayan, E., Thompson, R. A., and Godfrey, S. (2016). The relationship between physiological stress and wildlife disease: consequences for health and conservation. *Wildlife Research* **43**; 51-60. doi: 10.1071/WR15183

International Association for the Study of Pain. (2016). Pain. Available at http://www.iasp-pain.org/Education/Content.aspx?ItemNumber=1698&navItemNumber=576#Pain [Accessed: 24 January 2017].

Jackson W. J., Argent, R. M., Bax, N.J., Bui, E., Clark, G. F., Coleman, S., Cresswell, I. D., Emmerson, K. M., Evans, K., Hibberd, M. F., Johnston, E. L., Keywood, M. D., Klekociuk, A., Mackay, R., Metcalfe, D., Murphy, H., Rankin, A., Smith, D. C., Wienecke, B. (2016). Overview: Land-use change, and habitat fragmentation and degradation threaten ecosystems and resilience. In 'Australia State of the Environment 2016'. (Australian Government Department of the Environment and Energy, Canberra.) Available at https://soe.environment.gov.au/theme/overview/topic/land-use-change-and-habitat-fragmentation-and-degradation-threaten-ecosystems [Accessed: 20 April 2017]. doi: 10.4226/94/58b65510c633b

Jakob-Hoff, R. M., MacDiarmid, S. C., Lees, C., Miller, P. S., Travis, D., and Kock, R. (2014). Manual of procedures for wildlife disease risk analysis. (World Organisation for Animal Health and IUCN: Paris.)

Johnson, C., Cogger, H., Dickman, C., and Ford, H. (2007). Impacts of landclearing: the impacts of approved clearing of native vegetation on Australian wildlife in New South Wales' (WWF Australia: Sydney.)

Johnstone, C. P., Lill, A., and Reina, R. D. (2012b). Does habitat fragmentation cause stress in the agile antechinus? A haematological approach. *Journal of Comparative Physiology B* **182**, 139-155. doi: 10.1007/s00360-011-0598-7

Johnstone, C. P., Reina, R. D., and Lill, A. (2012a). Interpreting indices of physiological stress in free-living vertebrates. *Journal of Comparative Physiology* B **182**, 861-879. doi: 10.1007/s00360-012-0656-9

Jones, M., Hamede, M., and McCallum, H. (2012). The Devil is in the detail: conservation biology, animal philosophies and the role of animal ethics committees. In ‘Science Under Siege: Zoology Under Threat’. (Eds. P. Banks, D. Lunney, and C. Dickman.) pp. 79-88. (Royal Zoological Society of New South Wales, Mosman.) doi: 10.7882/FS.2012.040

Kanowski, J., Catterall, C., Wardell-Johnson, G. W., Proctor, H., and Reis, T. (2003). Development of forest structure on cleared rainforest land in eastern Australia under different styles of reforestation. *Forest Ecology and Management* **183**, 265-280.

Kavanagh, R. P., Stanton, M. A., and Brassil, T. E. (2007). Koalas continue to occupy their previous home-ranges after selective logging in *Callitris–Eucalyptus* forest. *Wildlife Research* **34**, 94-107. doi: 10.1071/WR06126

Kirkwood, J. K., Sainsbury, A. W., and Bennett, P. M. (1994). The welfare of free-living wild animals: methods of assessment. *Animal Welfare* **3**, 257-73.

Koolhaas, J. M., Korte, S. M., De Boer, S. F., Van Der Vegt, B. J., Van Reenen, C. G., Hopster, H., De Jong, I. C., Ruis, M. A. W., and Blokhuis, H. J. (1999). Coping styles in animals: current status in behavior and stress-physiology. *Neuroscience & Biobehavioral Reviews* **23**, 925-935.

Ladds, P. (2009). ‘Pathology of Australian Native Wildlife.’ (CSIRO Publishing: Melbourne.)

Lindenmayer, D. B., and Fischer, J. (2006). ‘Habitat Fragmentation and Landscape Change.’ (Island Press: Washington, DC.)

Lunney, D. (2012a). Ethics and Australian mammalogy: reflections on 15 years (1991–2006) on an Animal Ethics Committee. *Australian Mammalogy* **34**, 1-17. doi: 10.1071/AM10010

Lunney, D. (2012b). Wildlife management and the debate on the ethics of animal use. II. A challenge for the animal protection movement. *Pacific Conservation Biology* **18**, 81-99. doi: 10.1071/PC120081

Lunney, D. (2013). Wildlife roadkill: illuminating and overcoming a blind spot in public perception. *Pacific Conservation Biology* **19**, 233-249.

Machin, K.L. (2007). Wildlife analgesia. In ‘Zoo Animal and Wildlife Immobilization and Anesthesia.’ (Ed. G. West, D. Heard, and N. Caulkett.) pp. 43-60. (Blackwell Publishing: Ames, Iowa.)

Maron, M., Bull, J. W., Evans, M. C., and Gordon, A. (2015). Locking in loss: baselines of decline in Australian biodiversity offset policies. *Biological Conservation* **192**, 504-512. doi: 10.1016/j.biocon.2015.05.017

Maron, M., Ives, C. D., Kujula, H., Bull, J. W., Maseyk, F., Bekessy, S., Gordon, A., Watson, J. E. M., Lentini, P., Gibbons, P., Possingham, H. P., Hobbs, R. J., Keith, D. A., Wintle, B. A., and Evans, M. C. (2016). Taming a wicked problem: resolving controversies in biodiversity offsetting. *BioScience* **66**, 489-498. doi: 10.1093/biosci/biw038

May, J., Hobbs, R. J., and Valentine, L. E. (2016). Are offsets effective? An evaluation of recent environmental offsets in Western Australia. *Biological Conservation* (in press, published online). doi: 10.1016/j.biocon.2016.11.038

McAlpine, C., Brearley, G., Rhodes, J., Bradley, A., Baxter, G., Seabrook, L., Lunney, D., Liu, Y., Cottin, M., Smith, A. G., and Timms, P. (2017). Time-delayed influence of urban landscape change on the susceptibility of koalas to chlamydiosis. *Landscape Ecology* (in press, published online). doi:10.1007/s10980-016-0479-2

McAlpine C. A. , Fensham R. J., and Temple-Smith D. E. (2002). Biodiversity conservation and vegetation clearing in Queensland: principles and thresholds. *The Rangeland Journal* **24**, 36-55.

McDonald, L., Bradshaw, S. D., and Gardner, A. (2003). Legal protection of fauna habitat in Western Australia. *Environmental Planning and Law Journal* **20**, 95-115.

McEwan, A. B. (2016). The concept of violence: a proposed framework for the study of animal protection law and policy. PhD Thesis. (Australian National University: Canberra.)

McEwen, B. S. (2005). Stressed or stressed out: what is the difference? *Journal of Psychiatry & Neuroscience* **30**, 315-318.

McEwen, B. S., and Wingfield, J. C. (2003). The concept of allostasis in biology and biomedicine. *Hormones and Behavior* **43**, 2-15.

McIntyre, S., and Hobbs, R. (1999). A framework for conceptualizing human effects on landscapes and its relevance to management and research models. *Conservation Biology* **13**, 1282-1292.

McLeod, S., and Sharp, T. (2014). Improving the humaneness of commercial kangaroo harvesting. RIRDC Publication No. 13/116. (Australian Government Rural Industries Research and Development Corporation: Canberra.) Available at https://rirdc.infoservices.com.au/items/13-116 [Accessed: 24 January 2017].

McMahon, C. R., Hindell, M. A., and Harcourt, R. G. (2012). Publish or perish: why it's important to publicise how, and if, research activities affect animals. *Wildlife Research* **39**, 375-377. doi: 10.1071/WR12014

Metcalfe, D., and Bui. E. (2016). Land: Regional and landscape-scale pressures: Land clearing. In 'Australia State of the Environment 2016'. (Australian Government Department of the Environment and Energy, Canberra.) Available at https://soe.environment.gov.au/theme/land/topic/2016/regional-and-landscape-scale-pressures-land-clearing [Accessed: 21 April 2017]. doi: 10.4226/94/58b6585f94911

Mellor, D. J. (2016). Updating animal welfare thinking: moving beyond the 'Five Freedoms' towards 'Life Worth Living'. *Animals* **6**: 21. doi:10.3390/ani6030021

Mellor, D. J., Patterson-Kane, E., and Stafford, K. J. (2009). 'The Sciences of Animal Welfare.' (Wiley-Blackwell: Oxford.)

Menkhorst, P., Clemann, N., and Sumner, J. (2016). Fauna-rescue programs highlight unresolved scientific, ethical and animal welfare issues. *Pacific Conservation Biology* **22**, 301-303. doi: 10.1071/PC16007

Miller, G., and Patronek, G. (2016). Understanding the effects of maltreatment on animal welfare. In 'Animal Maltreatment: Forensic Mental Health Issues and Evaluations'. (Eds. L. Levitt, G. Patronek, and T. Grisso.) pp. 197-233 (Oxford University Press: Oxford.)

Miller, G. S., Small, R. J., and Meslow, E. C. (1997). Habitat selection by spotted owls during natal dispersal in western Oregon. *The Journal of Wildlife Management* **61**, 140-150.

Moberg, G. (2000). Biological response to stress: implications for animal welfare. In 'The Biology of Animal Stress: Basic Principles and Implications for Animal Welfare'. (Eds. G. Moberg and J. Mench.) pp. 1-21. (CABI Publishing: United Kingdom.)

Morgan, K. N., and Tromborg, C. T. (2007). Sources of stress in captivity. *Applied Animal Behaviour Science* **102**, 262-302.

Mosley, C. (2011). Pain and nociception in reptiles. *Veterinary Clinics of North America: Exotic Animal Practice* **14**, 45-60.

Narayan, E. J. (2015). Evaluation of physiological stress in Australian wildlife: embracing pioneering and current knowledge as a guide to future research directions. *General and Comparative Endocrinology* (in press, available online). doi: 10.1016/j.ygcen.2015.12.008

Narayan, E.J., and Williams, M. (2016). Understanding the dynamics of physiological impacts of environmental stressors on Australian marsupials, focus on the koala (*Phascolarctos cinereus*). *BMC Zoology* (2016) **1**, 2. doi:10.1186/s40850-016-0004-8

National Health and Medical Research Council. (2013). Australian code for the care and use of animals for scientific purposes, 8th edition. (National Health and Medical Research Council: Canberra.)

Newell, G. R. (1999). Responses of Lumholtz's tree-kangaroo (*Dendrolagus lumholtzi*) to loss of habitat within a tropical rainforest fragment. *Biological Conservation* **91**, 181-189.

Nussbaum, M. C. (2006). 'Frontiers of Justice: Disability, Nationality, Species Membership.' (Harvard University Press: Cambridge.)

Office of Environment and Heritage. (2013). Native Vegetation Regulation 2013: Environmental Outcomes Assessment Methodology. (Office of Environment and Heritage: Sydney.) Available at www.environment.nsw.gov.au/vegetation/eoam [Accessed: 20 April 2017].

Office of Environment and Heritage. (2014). Biodiversity legislation review – Office of Environment and Heritage paper 1: objects. (Office of Environment and Heritage: Sydney.) Available at http://www.environment.nsw.gov.au/resources/biodiversity/140864objects.pdf [Accessed: 21 April 2017].

Office of Environment and Heritage. (2016). NSW report on native vegetation 2013-14. (Office of Environment and Heritage on behalf of the NSW State Government: Sydney.) Available at www.environment.nsw.gov.au/vegetation/reports.htm [Accessed: 24 January 2017].

OIE. (2016). Terrestrial animal health code, 25th edition. (World Organisation for Animal Health: published online.) Available at http://www.oie.int/en/international-standard-setting/terrestrial-code/ [Accessed: 24 January 2017].

Pacioni, C., Eden, P., Reiss, A., Ellis, T., Knowles, G., and Wayne, A. F. (2015). Disease hazard identification and assessment associated with wildlife population declines. *Ecological Management and Restoration* **16**, 142-152. doi:10.1111/emr.12155

Panksepp, J. (2005). Affective consciousness: core emotional feelings in animals and humans. *Consciousness and Cognition* **14**, 30-80.

Paquet, P. C., and Darimont, C. T. (2010). Wildlife conservation and animal welfare: two sides of the same coin. *Animal Welfare* **19**, 177-190.

Paul-Murphy, J., Ludders, J. W., Robertson, S. A., Gaynor, J. S., Hellyer, P. W., and Wong, P. L. (2004). The need for a cross-species, approach to the study of pain in animals. *Journal of the American Veterinary Medical Association* **224**, 692-697. doi: 10.2460/javma.2004.224.692

Pearson, D., Shine, R., and Williams, A. (2005). Spatial ecology of a threatened python (*Morelia spilota imbricata*) and the effects of anthropogenic habitat change. *Austral Ecology* **30**, 261-274.

Powell, R. A., and Mitchell, M. S. (2012). What is a home range? *Journal of Mammalogy* **93**, 948-958. doi: 10.1644/11-MAMM-S-177.1

Pyne, S. J. (2015). 'Burning bush: a fire history of Australia.' (University of Washington Press: Seattle.)

Queensland Parliament. (2016). Record of Proceedings, 17 August 2016, p. 2934.

Radford, M. (2000).Towards a better understanding of animal protection legislation: the meaning of 'unnecessary suffering' explained. In 'Veterinary Ethics'. (Ed. Legood.) pp. 33-48 (Continuum: London; New York.)

Rhind, S. G. (2004). Direct impacts of logging and forest management on the brush-tailed phascogale *Phascogale tapoatafa* and other arboreal marsupials in a jarrah forest of Western Australia. In ‘Conservation of Australia’s Forest Fauna. 2nd edition.’ (Ed. D. Lunney.) pp. 639-655. (Royal Zoological Society of New South Wales: Mosman.)

Rhind, S. G. (1998). Ecology of the brush-tailed phascogale in jarrah forest of south-western Australia. PhD Thesis. (Murdoch University: Perth.)

Rhodes, J. R., Lunney, D., Callaghan, J., McAlpine, C. A. (2014.) A few large roads or many small ones? How to accommodate growth in vehicle numbers to minimise impacts on wildlife. *PLoS ONE* **9**, e91093. doi:10.1371/journal.pone.0091093

Ritchie, E. G., Bradshaw, C. J., Dickman, C. R., Hobbs, R. J., Johnson, C. N., Johnston, E. L., Laurance, W. F., Lindenmayer, D. B., McCarthy, M. A., Nimmo, D. G., Possingham, H. P., Pressey, R. L., Watson, D. M., and Woinarski, J. (2013). Continental-scale governance and the hastening of loss of Australia’s biodiversity. *Conservation Biology* **27**, 1133-1135. doi: 10.1111/cobi.12189

Rogers, L.J. (2010). Cognition and animal welfare. *Wiley Interdisciplinary Reviews: Cognitive Science* 1: 439-445.

RSPCA Australia. (2002). The Kangaroo Code Compliance Report: a survey of the extent of compliance with the requirements of the Code of Practice for the Humane Shooting of Kangaroos. Prepared for Environment Australia. (RSPCA Australia). Available at http://www.environment.gov.au/biodiversity/wildlife-trade/publications/kangaroo-shooting-code-compliance/contents [Accessed: 24 January 2017].

Sainsbury, A. W., and Vaughan-Higgins, R. J. (2012). Analysing disease risks associated with translocations. *Conservation Biology* **26**, 442-452. doi:10.1111/J.1523-1739.2012.01839.X

Sato, C. F., Wood, J. T., Schroder, M., Green, K., Osborne, W. S., Michael, D. R. and Lindenmayer, D. B. (2014). An experiment to test key hypotheses of the drivers of reptile distribution in subalpine ski resorts. *Journal of Applied Ecology* **51**, 13-22.

Saunders, D. A., Hobbs, R. J., and Margules, C. R. (1991). Biological consequences of ecosystem fragmentation: a review. *Conservation Biology* **5**, 18-32.

Saunders, D.A., Mawson, P., and Dawson, R. (2011). The impact of two extreme weather events and other causes of death on Carnaby’s Black Cockatoo: a promise of things to come for a threatened species? *Pacific Conservation Biology* **17**, 141-8.

Schoepf, I., Pillay, N., and Schradin, C. (2016). The pathophysiology of survival in harsh environments. *Journal of Comparative Physiology B* **187**, 183-201. doi: 10.1007/s00360-016-1020-2

Schulte, P. M. (2014). What is environmental stress? Insights from fish living in a variable environment. *Journal of Experimental Biology* **217**, 23-34. doi: 10.1242/jeb.089722

Seabrook, L., McAlpine, C., and Fensham, R. (2006). Cattle, crops and clearing: regional drivers of landscape change in the Brigalow Belt, Queensland, Australia, 1840–2004. *Landscape and Urban Planning* **78**, 373-385.

Semlitsch, R., Conner, C., Hocking, D., Rittenhouse, T., and Harper, E. (2008). Effects of timber harvesting on pond-breeding amphibian persistence: testing the evacuation hypothesis. *Ecological Applications* **18**, 283-289.

Semlitsch, R. D., Todd, B. D., Blomquist, S. M., Calhoun, A. J., Gibbons, J. W., Gibbs, J. P., Graeter, G. J., Harper, E. B., Hocking, D. J., Hunter Jr, M. L., and Patrick, D. A. (2009). Effects of timber harvest on amphibian populations: understanding mechanisms from forest experiments. *Bioscience* **59**, 853-862. doi:10.1525/bio.2009.59.10.7

Sharp, T., and Saunders, G. (2011). A model for assessing the relative humaneness of pest animal control methods. 2nd edition. (Australian Government Department of Agriculture, Fisheries and Forestry: Canberra). Available at http://www.agriculture.gov.au/animal/welfare/aaws/humaneness-of-pest-animal-control-methods [Accessed: 24 January 2017].

Shine, R., and Fitzgerald, M. (1996). Ecology of carpet pythons *Morelia spilota* (Serpentes: Pythonidae) in coastal eastern Australia. *Biological Conservation* **76**, 113-122.

Sih, A., Ferrari, M. C. O., and Harris, D. J. (2011). Evolution and behavioural responses to human-induced rapid environmental change. *Evolutionary Applications* **4**, 367-387. doi: 10.1111/j.1752-4571.2010.00166.x

Sonter, L. J., Tomsett, N., Wu, D., and Maron, M. (2016). Biodiversity offsetting in dynamic landscapes: influence of regulatory context and counterfactual assumptions on achievement of no net loss. *Biological Conservation* (in press, published online). doi: 10.1016/j.biocon.2016.11.025

Steimer, T. (2002). The biology of fear- and anxiety-related behaviors. *Dialogues in Clinical Neuroscience* **4**, 231-249.

Tablado, Z. and Jenni, L. (2017). Determinants of uncertainty in wildlife responses to human disturbance. *Biological Reviews* **92**, 216-233. doi:10.1111/brv.12224

Taylor, M. F. J., and Dickman, C. R. (2014). NSW *Native Vegetation Act* saves Australian wildlife. (WWF-Australia: Sydney.)

Thompson, S. A., and Thompson, G. G. (2015). Fauna-rescue programs can successfully relocate vertebrate fauna prior to and during vegetation-clearing programs. *Pacific Conservation Biology* **21**, 220-225. doi: 10.1071/PC14922

Thompson, S. A., and Thompson, G. G. (2016). Response to 'Fauna-rescue programs highlight unresolved scientific, ethical and animal welfare issues' by Menkhorst *et al. Pacific Conservation Biology* **22**, 304-307. doi: 10.1071/PC16015

Turnbull, C., Beadle, C., Traill, J., and Richards, G. (1992). Benefits, problems and costs of excavators and bulldozers used for clearing operations in Southern Tasmania. Technical report. (CSIRO Division of Forestry: Tasmania.)

Twigg, L. E., and Parker, R. W. (2010). Is sodium fluoroacetate (1080) a humane poison? The influence of mode of action, physiological effects, and target specificity. *Animal Welfare* **19**, 249-263.

Tyndale-Biscoe, C. H., and Smith, R. F. (1969). Studies on the marsupial glider *Schoinobates volans* (Kerr). III. Response to habitat destruction. *Journal of Animal Ecology* **38**, 651-659.

Valentine, P. (2004). The demise of mass migration of the Brown Awl *Badamia exclamationis* (Fabricius 1775) (Lepidoptera: Hesperiidae): a consequence of land clearing in Queensland? *Pacific Conservation Biology* **10**, 67-69.

van der Hoop, J., Corkeron, P., and Moore, M. (2017). Entanglement is a costly life-history stage in large whales. *Ecology and Evolution* **7**, 92-106. doi: 10.1002/ece3.2615

Vogelnest, L. and Woods, R. (2008). 'Medicine of Australian Animals.' (CSIRO Publishing: Melbourne.)

Vogelnest, L. and Woods, R. (2015). 'Radiology of Australian Animals.' (CSIRO Publishing: Melbourne.)

Wardell-Johnson, G., Calver, M., Saunders, D., Conroy, S., and Jones, B. (2004). Why the integration of demographic and site-based studies of disturbance is essential for the conservation of jarrah forest fauna. In 'Conservation of Australia's Forest Fauna. 2nd edition.' (Ed. D. Lunney.) pp. 394-417. (Royal Zoological Society of New South Wales: Mosman.)

Weary, D. M., Neil, L., Flower, F. C., and Fraser, D. (2006). Identifying and preventing pain in animals. *Applied Animal Behaviour Science* **100**, 64-76.

White, S. (2009). Animals in the wild, animal welfare and the law. In 'Animals Law in Australasia.' (Eds. P. Sankoff and S. White.) pp. 230-258. (The Federation Press: Sydney.)

Wiggins, N. L., Williamson, G. J., McCallum, H. I., McMahon, C. R., and Bowman, D. M. J. S. (2010). Shifts in macropod home ranges in response to wildlife management interventions. *Wildlife Research* **37**, 379-391. doi: 10.1071/WR09144

Williams, J., Read, C., Norton, A., Dovers, S., Burgman, M., Proctor, W. and Anderson, H. (2001). Biodiversity, Australia State of the Environment Report 2001 (Theme Report). (CSIRO Publishing on behalf of the Department of the Environment and Heritage: Canberra.) Available at http://webarchive.nla.gov.au/gov/20130904221249/http://www.environment.gov.au/soe/2001/publications/theme-reports/index.html [Accessed: 28 April 2017].

Wingfield, J. C. (2005) The concept of allostasis: coping with a capricious environment. *Journal of Mammalogy* **86,** 248-254. doi: 10.1644/BHE-004.1

Wobeser, G. A. (1981). ‘Diseases of Wild Waterfowl.’ (Plenum Press: New York.)

Wobeser, G. A. (2006). ‘Essentials of Disease in Wild Animals.’ (Blackwell Publishing: Ames, Iowa.)

Zachary, J. F., and McGavin, M. D. (2012). ‘Pathologic Basis of Veterinary Disease. 5th edition.’ (Elsevier: St Louis.)

TABLE

Table 1. Definitions and descriptions of pathological conditions that animals may experience in environments in which vegetation has been removed. Key to sources: Zachary and McGavin 2012[1]; Hing *et al.* 2016[2]; Brearley *et al.* 2013[3]; Wobeser 2006[4]; Ladds 2009[5]; Vogelnest and Woods 2008[6]; Wiggins *et al.* 2010[7]; Pacioni *et al.* 2015[8]; Acevedo-Whitehouse and Duffus 2009[9]; Cooper 2013a[10]; Hanger and Nottidge 2009[11]; International Association for the Study of Pain 2016[12]; Bateson 1991[13]; Cooper and Cooper 2013[14]; McEwen and Wingfield 2003[15]; Narayan and Williams 2016[16])

Pathological condition	Description
Deceleration injury	Blunt impact trauma incurred when the body in motion is forcibly stopped, however due to inertia the body cavity contents continue in the line of motion. The brain in particularly vulnerable.
Dehydration	Excessive loss of water from the body, occurring in several ways (e.g. inadequate intake of food, diarrhoea, vomiting). It can result in inadequate tissue perfusion and electrolyte imbalances and, ultimately, death (i.e. hypovolaemic shock).[1]
Disease	Wobeser (2006) defines disease as ‘any impairment that interferes with or modifies the performance of normal functions, including responses to environmental factors such as nutrition, toxicants, and climate; infectious agents; inherent or congenital defects; or a combination of these factors’. Therefore, disease is a heterogeneous term, capturing any dysfunction or perturbation in normal physiologic homeostasis and there is a spectrum, ranging from mild and clinically insignificant, through to severe and life threatening.

Disease transmission (increased likelihood of)	The loss of vegetation and possible dispersal to a new habitat may alter intra- and inter-specific contact rates and vector (e.g. ticks, mosquitos) and host densities, thus increasing the likelihood of vector-borne or direct transmission of infectious disease.[2,3,4]
Exertional (capture) myopathy (rhabdomyolysis)	A degenerative disease characterised by muscle damage, usually following extreme exertion, struggle and/or stress and potentially exacerbated by high ambient temperature, nutritional deficiencies and electrolyte depletion (dehydration).[1,5,6,7] It may occur when animals are pursued, entangled/entrapped, or are panicked and fleeing. Although seen in a range of species including birds, it is most commonly diagnosed in macropods.[5]
Immune function (adversely affected)	Immune function refers to an animal's capacity to mount an immune response to a pathogenic (i.e. capable of causing disease) challenge. Conditions relating to land clearing such as chronic stress, inadequate energy intake, exposure to temperature extremes, and secondary infections of wounds sustained during clearing can adversely affect immune function (stress-induced immunosuppression), thereby making animals more susceptible to infectious disease and opportunistic pathogens (e.g. pneumonia, parasites).[8,9]
Maladaptation	Maladaptation is a circumstance of chronic stress in which an animal fails to adapt to its environment because of (e.g.) unfamiliarity with it, lack of necessary resources or of conspecifics to associate with, or adverse interactions with other animals.[5,10] Immune function and other normal function may be compromised.

Misadventure	Death that is caused by the animal interacting with its physical environment in some way. During clearing or during attempted dispersal, death could occur through (e.g.) vehicle strike, drowning or entanglement in fencing.[5,11]
Morbidity	The state of being diseased. It may also refer to the incidence or prevalence of a disease.
Mortality	The state of being dead. It may also refer to the incidence or prevalence of death.
Nutritional disease	Nutritional disease most often refers to a general nutritional deficiency (e.g. inadequate intake of proteins or calories, vitamin deficiency) and less commonly to disease due to nutritional excess or to some other nutritional disorder.[5] Inadequate or negative energy balance will result in resource partitioning, and potentially dampening of key systems/processes such as immune function, reproduction, and growth.[4]
Pain	An unpleasant sensory and psychological experience associated with actual or potential tissue damage.[12,13] Animals may experience pain if they sustain physical injuries or are experiencing tissue damage because of some other pathological condition. Pain comprises heterogeneous categories (e.g. deep pain, visceral pain, cutaneous pain), which vary significantly in their quality, duration, and function and, further, gradation exists, ranging from low level and relatively tolerable (at least in the short-term) through to unbearable.

Pathologic conditions/pathologies	A state indicative of or caused by disease, rather than that which occurs physiologically as a result of homeostasis. Therefore, a pathogen is any agent (infectious or not) that is capable of causing disease (e.g. infectious agents such as viruses, bacteria and parasites and non-infectious agents such as toxins, adverse environmental conditions, and nutritional deficiencies or excesses).
Predation	Death due to attack by a native or non-native predator, or by a domestic animal.
Reproduction (adverse effects on)	The reproduction of animals may be affected by a reduction in fertility or reproductive output, or in survivorship of offspring, because of (e.g.) the death of offspring at foot or *in utero* or a failure to reproduce because of diminished body condition and diversion of resources (energy), the absence of a conspecific to mate with, or the lack of a suitable hollow or other nest site.[4,9]
Reservoir	An animate (e.g. any animal or plant) or inanimate (e.g. soil, water) nidus/host of an infectious pathogen in which it normally lives. The pathogen primarily depends on the reservoir for its survival, and must also be able to multiply within it, typically without causing significant clinical disease within animate reservoirs. Significant clinical disease may eventuate in a susceptible host following transmission.
Shock	A physiological response to diverse causes such as trauma resulting in haemorrhage and hypovolaemia or other challenge, involving inadequate blood flow to tissues, cardiovascular collapse, and cellular hypoperfusion and hypoxia that can be life threatening.[1,14]

Stress and stressors	The optimal state of equilibrium (homeostasis) is constantly challenged by intrinsic and extrinsic forces, which are known as stressors (which may be multiple and may interact). Duration and frequency of stress is central to its significance. In general, a short-term response is an adaptive ‘emergency’ allostatic response that promotes survival until the stressor(s) subside(s) as well as a return to homeostasis, and is functional (i.e. physiological). However, prolonged and or frequent stress causes allostatic overload and can be maladaptive (i.e. pathological), potentially resulting in a variety of dysfunctions (i.e. disease), including adverse effects on immune and reproductive function.[4,15]
Stress-related pathology	Animals may experience maladaptation and chronic stress because of sustained exposure or anticipation of biotic (e.g. predators, hostile conspecifics) or abiotic (e.g. suboptimal environmental conditions) stressors, which may have adverse effects on physiologic functions and thereby on body condition, growth, immune function and reproduction.[2,4,5,16]
Temperature-related injuries	Injuries due to hyperthermia or hypothermia due to excessive or extreme heat or cold arising because of lack of shelter or cover and changes in microclimates.[5,6] Burns may occur if debris is burned.
Traumatic injury	Injury caused by a sudden, violent force resulting in the compression, stretching, avulsion, torsion, fracturing or penetration of tissue, as well as haemorrhage.[14]

Vector	Any living creature that transmits disease from one host to another. Typically the term applies to arthropods (e.g. mosquitoes, ticks, biting flies).