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# Evaluation of physiological stress in Australian wildlife: Embracing pioneering and current knowledge as a guide to future research directions

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A B S T R A C T

Australia has a rich terrestrial and marine biodiversity and high species endemism. However, the oceanic continent is facing the biodiversity extinction crisis. The primary factors are anthropogenic induced environmental changes, including wildlife habitat destruction through urbanisation and predation by feral animals (e.g. red foxes and feral cats), increased severity of diseases (e.g. chytridiomycosis and chlamydia), and increased occurrence of summer heat waves and bush fires. Stress physiology is a dynamic field of science based on the studies of endocrine system functioning in animals. The primary stress regulator is the hypothalamo-pituitary adrenal (interrenal) axis and glucocorticoids (corticosterone and/or cortisol) provide stress index across vertebrate groups. This review paper focuses on physiological stress assessments in Australian wildlife using examples of amphibians, reptiles, birds and marsupials. I provide a thorough discussion of pioneering studies that have shaped the field of stress physiology in Australian wildlife species. The main findings point towards key aspects of stress endocrinology research, such as quantification of biologically active levels of glucocorticoids, development of species-specific GC assays and applications of stress physiology approaches in field ecology and wildlife conservation programs. Furthermore, I also discuss the importance of chronic stress assessment in wildlife populations. Finally, I provide a conceptual framework presenting key research questions in areas of wildlife stress physiology research. In conclusion, wildlife management programs can immensely benefit from stress physiology assessments to gauge the impact of human interventions on wildlife such as species translocation and feral species eradication.



## 1. Introduction

Australia is a "megadiverse" continent and it has unique wildlife biodiversity, with 87% of mammal species, 93% of reptiles, 94% of frogs and 45% of bird species only found in Australia (Chapman, 2008). Unfortunately, Australia also has had the largest number of mammalian species extinctions and it also has had widespread species reductions (Ceballos and Ehrlich, 2002). On the global front, 1 out of 3 mammal extinctions in the last 400 years have occurred in Australia, and 29 native mammals have become extinct since European settlement in the 1800s. Comparatively, fewer losses of native land mammals have occurred from continental North America since European settlement therefore native wildlife extinctions in Australia have occurred at massive high rates (Woinarski et al., 2015). Most of the wildlife species decline, however, happened in remote areas in the vast deserts and tropical savannas of Australia. These are primarily due to predation by introduced species, particularly the feral cat, *Felis catus*, and European red fox, *Vulpes vulpes*, and changed fire regimes (Woinarski et al., 2015). Australia's unique biodiversity is declining rapidly, with more than 1700 species known to be threatened and at risk of extinction. Present key threats to wildlife species are a combination of anthropogenic induced changes, such as degradation and fragmentation of habitat and altered fire regimes, unsustainable use and management of natural resources, changes to the aquatic environment and water flows, invasive species and global climate change (EPBC Act, 1999). (See Fig. 1)

It is widely accepted that human-induced landscape change is one of the biggest environmental threat facing Australian wildlife. For example, Brearley et al. (2009), highlighted in their review paper that to achieve more successful conservation outcomes, there is an urgent need for understanding the causal links between the processes of human-induced landscape change and the associated influences of habitat fragmentation, matrix hostility and loss

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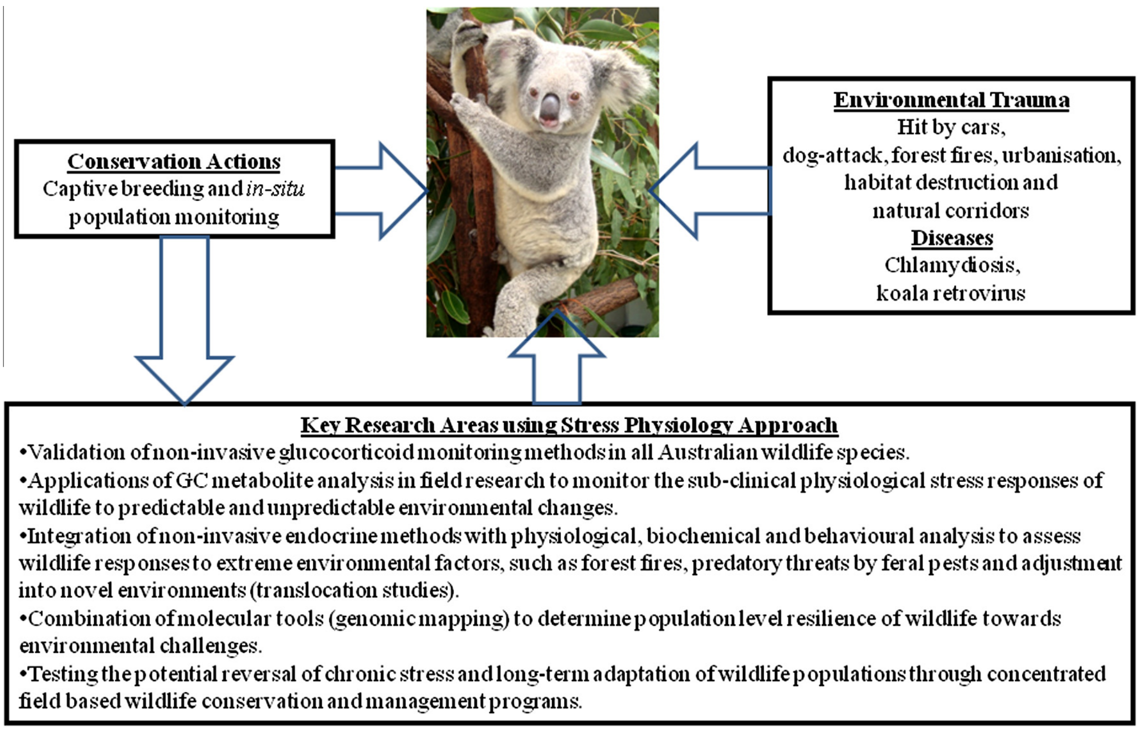


**Fig. 1.** Illustration of the important research questions using stress physiology approaches for wildlife conservation management programs. I have used the koala model, but the application is for broader native wildlife groups.

of connectivity on an animal's physiological stress response and disease susceptibility. Increased anthropogenic induced environmental change has also brought about the occurrence of more virulent and novel strains of pathogenic diseases and infections in wildlife species (Stalder, 2013). There is a need for research on causal relationships between environmental factors and host stress physiology to better understand the impacts of diseases on Australian marsupials (Hing et al., 2014).

Thus a range of environmental changes (anthropogenic changes) has led to wildlife species declines in Australia. These extreme environmental factors are acting as environmental stressors that challenge physiological systems (Gunderson and Stillman, 2015) to increase the fitness and chances of survival of animals (Wake and Vredenburg, 2008). One of the physiological systems important in this regard is the endocrine system and particularly the physiological stress hormone response. The neuroendocrine stress system is a highly organised and integrated system, which provides the physiological stress response required to maintain homeostasis, including chronic stress induced morphological plasticity, which leads to changes in cell size and physiological resilience to future stressors (Pfau and Russo, 2015). Therefore, it is important to assess the stress endocrine system in response to acute and chronic stressors in wildlife.

In this review paper, I provide a comprehensive account of the field and laboratory based research in the area of Australian wildlife stress endocrinology using examples of amphibians, reptiles, birds and small mammals. I will begin the discussions by describing the stress endocrine system and the methods used to quantify glucocorticoids (GCs). Then, I will discuss the importance of measuring baseline GCs levels in field studies that could provide important information on wildlife physiological responses to environmental stressors and management programs, such as species translocations. Furthermore, I will discuss the importance of incorporating endocrine measurements, in particular non-invasive stress hormone monitoring tools, in field based wildlife conservation and management programs because these physiological tools can provide vital information on the sub-clinical levels of stress in the study species, enabling conservation managers to make better interpretations of species vulnerability and resilience towards environmental perturbation factors and management interventions (e.g. invasive species control). Finally, I provide a conceptual framework to draw on important future research questions applying physiological approaches into wildlife conservation research.

## 2. Stress

The field of stress physiology was born in 1936, when Hans Selye characterized the stress response as a common set of generalized physiological responses that were experienced by all organisms exposed to a variety of environmental challenges, such as temperature change or exposure to noise. Stress is a term that is used across a broad spectrum of scientific research and, as a result, its definition is often ambiguous, and it is sometimes not defined at all (McEwen and Wingfield, 2003; Øverli et al., 2007). For the purpose of this review, a stressor (or stress event) will be defined as a noxious stimulant, which exposes the animal to stress or energetic costs outside of that required for predictable daily and seasonal requirements (Narayan, 2013). Sterling and Eyer (1988) introduced the term 'allostasis', which has been heavily advocated as the body's ability to adapt to stress (McEwen and Stellar, 1993).

### *2.1. Hypothalamus-pituitary adrenal/interrenal axis*

The hypothalamus-pituitary adrenal or interrenal axis (hereafter referred as the HPA-axis) is an ancient physiological system of vertebrates, which is organised in a hierarchical manner with feedback loops, and it plays a pivotal role in mediating organismal responses to environmental change (Denver, 2009). The structural organisation of the HPA-axis involves neurosecretory neurons