The potential role of zoos in climate change research and mitigation

Rebecca Spindler, Joanna Wiszniewski and David Slip

Taronga Conservation Society Australia, Bradleys Head Rd, Mosman, NSW 2088

ABSTRACT

Predicting how animal species might respond to climate change is an important step in developing effective tools for managing biodiversity in a changing climate. This task is made difficult due to a lack of reliable data on the animals and how they will respond to changes in their habitat. The collections of animals in zoos are an important resource that can be used to address some of the gaps in our knowledge, particularly when integrated with field research and conservation planning. Zoos can increase our understanding of the impact of wildlife disease by conducting integrated disease surveillance programs and developing treatment or management options. Reproductive technologies, validated in zoos, can provide value added census data to inform on population viability and function as well as numbers. Determining species preferences and tolerance limits will also inform the triggers that are likely to instigate migration, adaptation or extinction. Zoos offer a controlled environment that allows the examination of the impacts of interdependent factors such as dietary requirements, water tolerance, response to stressors and treatment of disease. Further, zoos maintain species in captivity as insurance against catastrophe in the wild. With additional data, emphasis could be placed on keystone species which will improve climate change resilience for the ecosystem and catchment area. Finally, zoos provide a resource to communicate the implications of climate change to the public and bring about behaviour change. In total, the skills developed in intensively managing small populations and opportunities presented by well managed, captive populations are underutilised and will become more relevant in implementing mitigation strategies for the management of biodiversity under a changing climate.

Key words: zoo, aquarium, wildlife, health, reproduction, species, ecosystem, function, mitigation, adaptation, management

Introduction

Climate is a fundamental determinant of where animals can live and impacts on how they establish, grow and reproduce. In the face of a changing climate, species in the wild will either persist where they are, adapt over generations and remain in the area, migrate to preferred conditions or if this is not available, go extinct (Hewitt and Nichols, 2005; Midgley *et al.*, 2005).

Accordingly, climate change can have a direct impact on biodiversity. However, in most cases it is difficult to make accurate predictions of the fate of species or habitats as a result of climate change because of a lack of reliable data. These predictions are important in developing effective tools for biodiversity management under changing climatic conditions. One way of addressing this lack of data is through the widespread and systematic integration of information gathered in the wild, in zoos (including aquaria) and through other research activities.

Despite the limited availability data explaining the impact of climate change on particular species and habitats, it is clear that well functioning ecosystems are likely to be more resilient to both the direct effects of climatic change and to indirect impacts such as disease prevalence, invasive species, changing hydrology and fire regimes (Folke, 2010; Folke *et al.*, 2004). The degree to which ecosystems are able to cope is unique to each habitat. For example, some alpine habitats are particularly susceptible to climate change impacts due to the unique and physical barriers that define their niche, whereas ecosystems that already tolerate a broad temperature band may be less susceptible to negative impacts.

In addition, some natural ecosystems contain one or more keystone or architectural species that effectively determine the structure and function of that ecosystem and the species networks within it. Understanding the impacts of climate change on these species is crucial in developing effective overarching management strategies. Currently few climate models include information on bio-feedback mechanisms that are likely to occur as a result of species decline, migration or altered function through phenotypic plasticity. These data are often difficult if not impossible to obtain in free-ranging populations alone. Collaborative research across free-ranging and captive populations is an under-utilised resource for understanding the forces at play under changing environmental conditions.

There are a number of key areas where knowledge deficits limit our ability to predict the impacts of climate change on ecosystem function. In this paper we examine some of these areas and suggest possible strategies for addressing some of these deficits. We also look at the potential roles that zoos can play in facilitating research on captive animals, integrating existing data sets and assisting the implementation of management strategies that incorporate this knowledge in a timely and relevant manner.

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Species Response to Climate Change and Ecosystem Implications

Bioclimatic models assume that current observed distributions of species are in equilibrium with the present climate and that species will be unable to establish, grow and reproduce outside of the modelled bioclimatic envelope. This is not necessarily the case. For example, in the southwest Australian floristic region the present distribution of plants cannot be explained by ecological factors alone (Yates *et al.*, 2007) and transplant experiments across climate gradients can show that some species will grow outside of their modelled distribution (Griffith and Watson, 2006).

How a species responds to a changing environment will also have an impact on interactions with surrounding species and therefore on the functionality of the ecosystem as a whole, as detailed here:

Species persistence: Some populations or species may tolerate a wide range of conditions and hence thrive in spite of climate change and subsequent environmental changes. Other species might remain in suboptimal habitat due to the scarcity of a critical resource in a more comfortable climate band. Under these circumstances, it is likely that species behaviour must adapt to suit the changed environment. In depth analyses are required to understand if any expected spatial, temporal or functional change in behavioural patterns of such populations causes a change in the role they play in the ecosystem. For example, populations may cease to provide the ecosystem services we traditionally ascribe to them, provide different or new services, the cost of behavioural adaptation may take a toll on health and individual function or the population may interact with a different range of species changing disease dynamics (for example if animals are active at altered times throughout the day).

a. *Adaptation over generations*: Sufficient plasticity and short generation times may allow some populations to adapt to changing climatic and habitat conditions. These changes are also likely to alter the role these species play in the ecosystem. In this case and that mentioned above, ecology, animal health, behaviour, nutrition and stress physiology will be important disciplines in determining the functionality of these individuals and their ecosystem as a whole. In each case, simple census information might indicate that an ecosystem is intact, but in reality the ecosystem may have changed fundamentally and may be deteriorating as a result of uncoupled species relationships.

b. *Migration*: In some situations whole ecosystems may slowly relocate as the climate changes. In other cases more mobile species may follow a food preference or more tolerable climate by migrating into areas that have become favourable but previously were not. These migrations can have a profound impact on the ecosystem into which the species move (France and Duffy, 2006; Gonzalez and Chaneton, 2002). The impact of species migration on both the original and the destination habitats must be assessed. Some native Australian species migrating to new habitats can cause havoc and disrupt ecosystem services in the area into which they have moved. In this case, a species considered to be native in the administrative jurisdiction (eg a state government authority) is behaving like, and having an impact akin to, an invasive species, and management action that treats the nominally native species as a pest species may be required to protect habitat health. The species-specific tolerance range and preferences that act as triggers for migration are unknown for most species, and must be clarified to increase the accuracy of predictive models.

c. *Extinction*: This is of greatest concern as reversibility is no longer an option. Zoos clearly provide an important resource in maintaining the option to introduce key architectural species to a habitat. The fight against the loss of species that have little impact on ecosystem function should be deprioritised to ensure the efficient use of resources. Conversely, current regulations that prohibit attempts to establish populations of species outside of traditional ranges should be reconsidered if these species will contribute to ecosystem function without causing further species decline. In many cases it is not known which species are crucial to maintaining the structure and function of an ecosystem. This knowledge is essential for prioritising mitigation action.

Species health and ecosystem function.

While the direct impact of climate change on animal health might include injury and illness due to extreme weather events, a more profound impact on animal health may come from the indirect impacts of climate change. For example, changes in climatic conditions might result in expanded distribution of disease vectors, pathogens, and parasites, increased interactions with conspecific and heterospecific individuals, malnutrition and changes in population structure or behaviour. Each of these changes can increase exposure and susceptibility to emerging infectious diseases (Daszak *et al.*, 2001; Relman *et al.*, 2008).

Figure 1. Tasmanian devils have not been seen on mainland Australia for 600 years, but re-introduction to select sites may provide ecosystem services and ensure the survival of the species. Photo, T. Britt-Lewis.

This is of great concern not only for the species in question but also for the downstream impacts on the function and integrity of important ecosystems through the loss of that species, or the infection of other key wildlife species (Daszak *et al.*, 2000). Wildlife species are also key reservoirs of diseases that have potentially devastating impacts on human and domestic animal health (Black *et al.*, 2001; Daszak *et al.*, 2000). Experimentation on the susceptibility of individuals and populations to disease is fraught with ethical and logistical issues. However, increased understanding of disease ecology and the factors that reduce population resistance to emerging disease will enhance our ability to predict the combination of pathogen, host and environmental conditions that are likely to lead to an outbreak.

Fortunately, there are already in place several opportunities to passively monitor wildlife health. Thousands of native species are brought to zoo and wildlife hospitals each year, as a result of trauma or signs of disease. This provides an opportunity for early detection of disease outbreaks as well as an opportunity to document disease status. Disease surveillance in combination with a widespread health database that is integrated across the wildlife, livestock, ecology and human health sectors is essential to the early detection and diagnosis of disease outbreaks and the coordination of mitigative action (Fig. 2; see http://www.arwh.org/). Zoos have already proved to be meaningful sources of information essential to the detection and management of zoonotic diseases such as the discovery of West Nile Virus in New York in 1999 (Steele *et al.*, 2000). Further, captive populations will continue to provide a unique resource to determine the effectiveness of a broad range of treatment options for a multitude of diseases across species (Aruji *et al.*, 2004; Hunter and Isaza, 2002).

A related area deserving of inquiry is the impact of climate change on habitat health and disease ecology. Because of the many challenges in refining the confounding factors that influence disease transmission patterns in a natural environment, few studies have tackled this question on a grand scale, although some have investigated potential relationships (Bodetti *et al.*, 2002). Ecosystems are continuously threatened by emergent diseases, invasive species, pollution, fragmentation and isolation and changing fire regimes. The compounding effects of these threats on biota and environmental and evolutionary processes are complex and require a comprehensive holistic and adaptive approach to predicting consequences for key habitats (Rapport *et al.*, 2001; Wobeser, 2003). Treatment of disease, reducing the risk of transmission and increasing resilience are all priority actions in maintaining ecosystem health and function that must rest on the foundation of sound biological information (Raymundoa *et al.*, 2009).

Figure 2. The Australian Registry of Wildlife Health at Taronga holds over 25 years of data, samples and records of wildlife pathology cases and disease investigations. An online environment provides access for collaboration and education.

Altered reproductive patterns as drivers of ecological change

Annual reproductive cycles are most often thought to be determined by daylength but there is now evidence to suggest that climate related factors may play a significant role for some species. For example species may be either:

1. subject to other triggers, as in the case of the maned wolf from Brazil which enters seasonal breeding during the same months, regardless of latitude and daylength (Songsasen *et al.*, 2006); or
2. plastic, as in the case of some turtle species responding to increased ambient temperatures by laying eggs earlier each year (Weishampel *et al.*, 2004). While offspring gender has been found to be skewed towards females in some species of turtle, (Hawkes *et al.*, 2007; Janzen, 1994), this plasticity of laying behaviour can result in a preponderance of males as sand temperature remains cooler (Weisrock and Janzen, 1999).

Species with plastic reproductive patterns, mediated by factors other than day-length, may be more likely to be impacted by significant changes in climate. Increased understanding of reproductive parameters and drivers will assist in efforts to manage and conserve such species (Wildt *et al.*, 2010). Improved understanding of reproductive biology and the use of assisted reproduction have contributed to increased fecundity of zoo based insurance populations, which has been important to the generation of self sustaining populations in the wild of species such as the Wyoming toad, whooping crane, black footed ferret, scimitar horned oryx (Wildt *et al.*, 2010). Technology currently exists to non-invasively examine reproductive and adrenal steroids of over 30 wildlife species, and the range of species being studied is expanding rapidly. The ability to detect the endocrine status of individuals has already been used to improve the understanding of the demographics of wild populations of inaccessible species (Burgess *et al.*, 2009) and to assist with free-ranging population management in species as diverse as whales, bears and owls (Hunt *et al.*, 2006; Wasser *et al.*, 2004; Wasser and Hunt, 2005). Techniques for the collection and cryopreservation of valuable genetic material developed in zoo-based populations can also contribute to genetic management of insurance populations and capture valuable genes of free-ranging populations at risk forever (Wildt *et al.*, 1997).

The development of each of these techniques has undergone an important phase of validation using the expertise of zoo staff and reliable long-term access to individuals and populations that is unique to captive environments. Even so, this is an underutilised resource and with greater cooperation with wildlife management agencies, zoo based populations could provide important information essential to better understanding and management of free-ranging populations of target species.

Changing availability of nutrients

Climate change is likely to have a dramatic impact on the abundance and distribution of prey resources for many species. While some species may be able to adapt, for others changes in food availability may significantly reduce their reproductive fitness and overall function. This is especially the case for wildlife populations that synchronise energy-consuming activities such as reproduction and migration with seasonal peaks in prey availability (Shultz *et al.*, 2009; Watanuki *et al.*, 2009). The development and validation of non-invasive techniques to identify diet composition of captive animals can greatly assist understanding the foraging ecology of wildlife species including those threatened by climate change (Hilderbrand *et al.*, 1996; Reich and Worthy, 2006).

Further, climate change may have profound impacts on marine environment as changes in ocean circulation or wind patterns may diminish up-welling of nutrient rich waters and affect the general productivity of continental shelf ecosystems (Barth *et al.*, 2007). Warming in the southern ocean may also reduce the amount of sea ice cover thus reducing productivity of the krill based ecosystem on which many marine mammals depend (Atkinson *et al.*, 2004). These changes will impact on the populations of marine mammals and may result in changes to abundance, distribution and migratory patterns of some species (reviewed in Simmonds and Isaac, 2007). For example, fragmentation and isolation of harbour porpoise populations in European waters has been strongly linked with recent climatic changes and succeeding changes in the food-web of the eastern North Atlantic Ocean (Fontaine *et al.*, 2010). Understanding how marine mammals and birds respond to climate change and the complex interaction between top down (the impact that top predators have on an ecosystem) and bottom up effects (the impact of key prey species such as krill) on marine ecosystems are important areas for understanding the impact of climate change. (Ainley and Hyrenbach, 2010).

Significant changes in environment conditions can also be identified by examining long term changes in diet of some species using long term markers within individual animals. For example chemical composition within the layers of teeth of marine mammals might give a decadal length indication of changes in diet and movement patterns (Mendes *et al.*, 2007), while the chemical composition along vibrissae of pinnipeds can be used to identify seasonal changes in diet and movement patterns over a number of years (Hall-Aspland *et al.* 2005). Many techniques used to study diet and movement patterns rely on assumptions that can be verified by experiments on captive animals (eg Casper *et al.* 2006; Hobson and Yohannes 2007)

Zoo-based studies can provide a much richer understanding of species' nutrient requirements and food preferences as a result of increasing temperatures and other environmental changes. For instance, zoos have the ability to conduct controlled feeding experiments of animals in a range of conditions to determine the degree of plasticity and tolerance levels across a wide range of species (Tovar *et al.*, 2009). The prevalence of neophobia (an aversion or fear of changed environments) can also be tested across species to determine the likelihood that wild populations will adapt to new food types and environments (Marples *et al.*, 2007). Moreover, the impact that introduced species have on ecosystems as a result of resource competition, for example, can also be more reliably predicted using the knowledge obtained from captive individuals' feeding preferences and foraging strategies (Barth *et al.*, 2000).

Figure 3. Researchers from the Australian Marine Mammal Research Centre use techniques validated at Taronga to better understand seasonal changes in diet of leopard seals. Photo: Victor Llampa

Investing in research that increases a) our understanding of ecological processes within terrestrial and marine system and; b) our ability to extrapolate data from individuals to the recent history of the environment, is important to our ability to predict and address the potential effects of climate change.

Increasing understanding of the impacts of climate change using captive populations

Zoos provide an important avenue for increased understanding of wildlife species, their environmental needs and preferences, and their ability to adapt. This has often filled an important gap in knowledge that cannot be gained from free-ranging populations because of cryptic animal behaviour, inaccessible environments, limited access to the animals and the likelihood of the study itself impacting on the animals being studied. Zoo-based populations provide access to individuals on a long term basis, providing context and life history parameters to single samples taken from captive or free-ranging individuals.

In addition to the resources available in any single zoo, the international network of zoos provides a breadth of experience and environmental conditions to which animals have adapted. Analysis of this wealth of data and experiments designed specifically to assess species tolerance will assist with estimating species plasticity and important elements of species survival, not available from any other source.

The benefit of a controlled environment such as that provided by a zoo offers a greater capacity to separate out confounding factors such as dietary requirements, temperature tolerance, water requirements, response to stressors and response to treatment for disease. Examining the isolated and collective impact of these factors will provide greater predictability and therefore better management decisions.

These data may be useful as isolated studies or to be fed into models predicting the impact of changing climate on biodiversity. The usefulness of any model is highly dependent on the quality of the information that is used to establish the model's parameters. Zoos provide an opportunity for experimentation to determine ecophysiological parameters through species preferences and plasticity (Tovar *et al.*, 2005)

The potential role of zoos in climate change mitigation

Flexibility of response is enhanced by a large and diverse range of tools at the disposal of the management teams to reconstruct ecosystem function. For example, management actions might include translocation of species, provision of native species in order to occupy key niches and ecosystem functions, the development of sustainable methods to eliminate or contain pest species, and undertake disease monitoring and risk management posed by or to wildlife.

Zoos provide insurance programs to conserve species and genetic diversity. To be most effective, programs should be coordinated and prioritised in line with state and national priorities for recovery and translocation programs. These programs should employ the wealth of zoo experience and managed on a scientific basis to provide an effective, reliable safety net for species essential to ongoing mitigation efforts. Joint forward planning and integration with agencies managing free-ranging and captive populations will aid the development of collaborative multidisciplinary programs targeting restoration of ecosystem function. Along with facilities suitable for short and long term holding of wildlife populations (including gene storage in liquid nitrogen) and existing populations of valuable species, zoos provide many tools allowing flexibility and efficiency for large scale ecosystem management. Any reintroduction or translocation program must be aware of the potential risk of disease transfer and should adhere to all IUCN guidelines (Kock *et al.*, 2010). Further, the knowledge of species health and response to treatment being developed in zoos should be applied to management plans to allow for rapid response such as vaccination, isolation or quarantine of a population or area, and emergency management and disaster preparedness to minimise the impacts of disease across ecosystems.

Zoos also provide a resource to communicate with a large audience through appropriate interpretations and presentations which can be harnessed to inform the public of the implications of climate change. Targeted public information campaigns can focus on behaviour change to encourage best practise mitigation and adaptation behaviour in individuals across society.

Finally, as management of wilderness areas and species becomes more intense, the skills that are developed and practised repeatedly in zoos will be in greater demand. Natural resource management teams have the opportunity to tap into valuable resources provided by zoo staff that have expertise in areas such as animal handling and small population management. Highly skilled veterinary, husbandry, scientific staff and other zoo professionals could be called on to act as part of integrated natural resource management teams to implement adaptive and mitigation strategies.

In conclusion, zoo based insurance populations, research opportunities, education resources and staff expertise represent powerful tools to add to the toolbox of biodiversity assessment and conservation in the face of climate change.

Figure 4. With over 14 million visitors a year and over 400,000 students engaged in zoo-based environmental education programs, the potential for Australian zoos to be a hub for behaviour change is significant. Photo: Rod Cheal

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