10 Potential impacts of climate change on terrestrial biodiversity

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10.1 Introduction

That the climate is going to change is as inevitable as the change that has happened in the past. This has led to great fears for the biodiversity across the globe, with Kakadu having been identified as a hotspot for biodiversity loss in the near future (Garnaut 2008). However, Kakadu is both large and diverse and the changing climate will affect different species, ecosystems and landscapes in quite different ways depending on their location and adaptive capacity. In this short paper we review the current state of knowledge about the impacts of climate change on Kakadu's biodiversity, describe what we consider to be the main threats and why, outline potential ways of maintaining the resilience of the Park as the climate changes and identify areas where more knowledge is needed.

10.2 What do we know?

While the most recent report on climate change in Australia (CSIRO & Australian Bureau of Meteorology 2007) is equivocal about rainfall in the Kakadu region over the next half century, three trends are almost inevitable – temperatures will rise, particularly the number of exceptionally hot days, cyclones will get stronger (Elsner et al 2008) and sea level will rise (IPCC 2007).

However we are also acquiring increasing knowledge of past climates which almost all species currently present in Kakadu have successfully survived. For instance 20,000 years ago the sea level was much lower than today and Kakadu was well inland (Nix & Kalma 1972). While the global ice age climate would have been cooler than today, the more continental location of Kakadu is likely to have resulted in far greater fluctuation in temperature, with extremes both higher and lower than currently occur. Rainfall was almost certainly lower at that time. Later sea level rise brought mangroves almost to the base of the sandstone cliffs (Woodroffe et al 1985). Even as recently as 500 years ago Magela floodplain, today a prolific wetland, was a savanna woodland (Wasson et al 2010). At this time we do not know where the wetland birds survived, probably in swamps now inundated with seawater, but few would have lived within the current borders of what we know as Kakadu National Park.

Such extremes of climate will have winnowed out some species through natural selection. And we have documentary evidence in the form of cave paintings that species like the Thylacine and the Tasmanian Devil succumbed to previous rapid environmental change and/or the influence of humans and dingoes. However, this previous winnowing means that those species which have survived are likely to be reasonably adaptable, with the genetic variability or ecological flexibility to withstand substantial climatic stress. This is likely to be particularly true of the sandstone endemics. While many savanna woodland and wetland

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species probably followed changing rainfall and temperature gradients north and south, sandstone species must have evolved in situ and have withstood everything thrown at them since. Of course, the deeply dissected and rugged stone country offers a particularly wide range of environmental settings (and consequently microclimates), from very sheltered ever-moist canyons to baking rock faces, over very short distances, allowing the option of responding to regional-scale climatic changes by spatial re-arrangement of their populations within distances as short as metres or a few kilometres.

10.3 What are the main threats?

Although Kakadu's terrestrial biodiversity has survived much variation in the past, the current bout of climate change is different and its consequences difficult to predict. This is because:

- we are not really sure how climate will change: how much, where, and when
- some species will be affected more by extrinsic climate change (eg loss of habitats elsewhere) than by climate change in the area we are specifically considering
- as we enter uncharted climatic conditions, we can't be sure how species and environments will respond – ie we're extrapolating beyond the bounds for which we have data
- many climate change impacts may be complex, and there are likely to be unexpected synergies between fire, exotic species and other processes. Thus species survival may be dictated not so much by individual species responses but by the responses of a myriad other species (eg species A may actually like warmer temperatures, but if its competitor, species B, likes warmer temperatures even more, species A will be disadvantaged).

Certainly three changes are new within the evolutionary history of many Kakadu species, high temperatures, increased levels of atmospheric carbon dioxide and stronger cyclones. And sea level may reach more extreme levels than at any time in the last million years.

Change in temperature may directly affect those reptile species that have temperature-related sexual determination of eggs, including crocodiles and some turtles, so may unbalance their sex ratios. The changing temporal patterning of temperature may change fruiting and flowering patterns in plants; emergence times in diapausal insects; triggers for migration in highly dispersive species; availability of water (permanence of pools and streams) and the life that depends upon it; thermoregulation, behaviours and foraging efficiency of animals; respiration, growth rates and competitive ability of plants; fire characteristics; breeding success for many species; and habitat suitability. Many existing interspecific relationships may be decoupled (eg emergence times for butterflies and availability of host plants), and specialised species may be particularly susceptible. Stresses during late dry season are likely to be increased. Fires are likely to be more intense and increased temperatures may favour some exotic plants, animals and diseases.

An example of limits to temperature adaptation is well demonstrated well by the spread of the cane toad *Chaunus marinus*. Over the past two decades toads have been able to adapt to average summer maximums of about 37.7^{o}C (Urban et al 2007). While this greatly expands their possible range, the capacity of toads to occupy climatic regimes beyond that temperature limit has evidently reached a physiological ceiling which they do not have the genetic potential to exceed. Such physiological thresholds can sometimes be at far lower temperatures, as is the case with some upland possums from Queensland (Williams et al 2003). The limits for most native Kakadu species are unknown.

Carbon dioxide can act like a fertiliser for plants, allowing them to use water more efficiently and grow faster. Higher levels of CO_2 favours some species groups, such as shrubs and trees, over others, such as many tropical grasses. How this plays out in terms of vegetation structure remains to be seen but woody thickening and the expansion of rainforest patches (eg Banfai & Bowman 2006) can be interpreted as a manifestation of this already happening.

Cyclones probably keep the forests in coastal regions of northern Australia at subclimax levels (Bowman & Panton 1994). Stronger cyclones will cause even more damage to standing trees and occasionally cause great loss of life among both plants and animals. Hollow-bearing trees, and their dependant fauna, will almost certainly become less common. The other main threat from cyclones is that there are now new exotic species in the Park which occupy disturbed ground more rapidly than native species. The propagules of weeds such as mission grass *Setaria* spp and gamba grass *Andropogon gayanus* are likely to be spread further by cyclones into areas the cyclones have disturbed. The short-term loss of forest canopy post-cyclone in these areas may trigger ideal conditions for these exotic grasses to establish and flourish. These new foci of infection will be hard to find and eradicate because the disturbance could be anywhere, allowing weed recruitment not just along roads as is currently the case with most anywhere. The damage from stronger cyclones will also change fuel loads and fire intensities in the times after the cyclone has passed, which have knock-on effects on the structure and function of the affected savanna landscapes.

The familiar landscapes of Kakadu will also be the main casualty of sea level rise as mangroves push back over the freshwater swamps. Just where and when such changes will occur will be difficult to predict. As the more seaward of the mangroves die, the most coastal sediments will be released and coastal architecture will be altered in ways that are difficult to predict. The more extreme predictions of sea levels rise, however, will eventually overwhelm all the most productive coastal wetlands leaving the less fertile laterite plains to abut the sea. Substantial reductions of lowland freshwater biodiversity can be expected at this time. Even the area of mangrove ecosystems, which are likely to expand, will become smaller again as the sea above the coastal plains becomes too deep. As in previous changes in sea level, however, it is unlikely that all the freshwater species will disappear, they will simply become more restricted and less common.

10.4 How do we maintain resilience?

Management responses to climate change impacts upon terrestrial biodiversity may be worth considering relative to:

- likelihood
- ability (and cost) for us to mitigate
- severity of impact
- flow-on consequence
- rapidity

For example, floodplain sedgelands will almost certainly be affected, the impact will be severe, and there will be substantial consequential effects on other biota, but it is unlikely to occur for 20 years so we may be able to come up with some remedial measures. Under such circumstances developing such measures is probably a high priority.

That said there are some principles that should underpin management of a site like Kakadu. For instance there is a temptation for the rarest species in any landscape to be considered insignificant and therefore not worth saving. However very rare species can play significant roles in ecosystem functioning (Zavaleta & Hulvey 2004) and, under changing climatic conditions, selection pressures alter and uncommon species can prosper. Thus today’s losers can be tomorrow’s winners, and provide ecological functions that would not have been possible had they become extinct. A resilient system needs untapped redundancy (Walker et al 2002), whether that be a surfeit of individuals or of species. Only with such redundancy do ecosystems have the capacity to re-establish the functions they had before they were disturbed. Thus there are sound ecological reasons, as well as legal obligations, for every species currently in Kakadu to be conserved if at all possible. Any temptation to institute a process of triage, whereby species at some arbitrary level of rarity are neglected and their millions of years of evolutionary history allowed to peter out, should be resisted. Such an approach, of course, should apply under existing threats as well as under the additional threats that will be generated by climate change. Just how such conservation will occur is a separate debate, determined on a species by species basis.

Resilience is far more difficult to maintain in the face of rising sea levels. In fact landscapes and ecological communities as a whole are more difficult to conserve than their component species because they often consist of multiple species on different ecological trajectories that occur together at a particular time and place, then disperse as conditions change. Thus, with landscapes, a triage is entirely appropriate, in fact the only strategy that can sensibly be adopted. The landscapes that will change most dramatically are the freshwater wetlands, just as they have always done through evolutionary history. Even so sea level rise will be gradual and some freshwater wetlands will persist longer than others. These are probably the most valuable in the medium term, and it is on them that management should be concentrated, particularly to attempt to diminish the detrimental impacts of their load of exotic organisms. It may even be appropriate to adopt more heroic conservation responses, such as through translocation of wetland elements to systems further inland and/or through the use of physical barriers to seawater intrusion where environmental engineering is conceivable. In the meantime the mangrove systems most likely to replace the freshwater swamps are also richly biodiverse, and warrant celebration even as their predecessors are being salinised.

Any increase in resilience under a regime of stronger cyclones will need to be built round responses to changes in vegetation. More vigilant fire management and a rapid response to weeds will be critical. For timely weed control after a cyclone, contingency plans need to be in place identifying potential sources of propagules and likely patterns of spread. Surveys and eradication in the year immediately following a cyclone may save years of control expenses if the weeds are allowed to linger longer.

10.5 What are the information gaps?

For each threat and resilience strategy there are gaps in knowledge that, if filled, are likely to improve response efficacy. Management of climate change in Kakadu will be greatly enhanced with better information on:

- likely climate change at a regional scale derived from finer scale climate change models;
- climatic associations, tolerance and drivers of at least representative species;
- trends in species and landscapes derived from monitoring programs that allow detection of climate change impacts, and early indication of unanticipated trajectories;

- probabilities of change derived from risk analysis frameworks which can then be used to prioritise management responses.

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