MANAGING PEST SPECIES UNDER CLIMATE CHANGE: RISKS AND OPPORTUNITIES

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ABSTRACT (SUMMARY)

Human activity is driving significant changes in global and regional climate systems through the enhanced greenhouse effect (IPCC 2007). Global climate models predict that this anthropogenic forcing will alter both mean climate parameters and the frequency and magnitude of extreme meteorological events (e.g. heat waves, severe storm events and droughts). Such changes may have significant destabilizing effects, decoupling existing relationships between species, altering species distributions and challenging current management regimes. However, they may also provide significant management opportunities.

Many pest species are expected to expand their geographical range in a warmer, more extreme, climate. Despite this, there is likely to be great variation both in pest species responses to changing climatic conditions and impacts on ecological and production systems, and in the effectiveness of current pest management strategies. This implies a need for ongoing monitoring and assessment of pest species responses to environmental change and management at local and regional scales. It also indicates a need for research aimed at identifying potential tipping points (or critical thresholds) in relation to significant meteorological events.

This presentation will focus on the role of risk assessment in decision-making for pest species management under uncertainty. Probabilistic modelling approaches, such as Bayesian Belief networks, provide a valuable adjunct to monitoring and evaluation programs. They facilitate the synthesis of current knowledge (including expert opinion), highlight critical knowledge gaps, and provide a basis for both targeted research and adaptive management. Integrated modelling to predict invasive species response to management under variable climatic conditions can be used to identify key opportunities for management which will contribute disproportionately to effective pest species control. Pest species management programs under future climatic regimes are likely to require the capacity for more adaptive and strategic response, and will need to be supported by flexible investment strategies which enable timely (adaptive) responses at critical periods.

Keywords: climate change, climate extremes, pest species, environmental risk, management opportunities, scenario modelling.

INTRODUCTION

Alien species invasions are recognised as a primary cause of global biodiversity decline (e.g. Vitousek *et al.* 1997). Australia has wild populations of over 80 introduced vertebrate species (Hart and Bomford 2006), and gains some 20 new potentially invasive animal species every year (Low 2008). This is in addition to invasive plant species; invasive diseases, fungi and parasites; introduced insects and other invertebrates; and introduced marine pests. Invasive species represent significant threats to native species and ecosystems, and constitute 13 of the 19 ‘key threatening processes’ identified under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). They also represent a significant threat to agriculture and a major financial burden to society (e.g. Mcleod 2004, Sinden *et al.* 2004).

At the same time, human activity is driving significant changes in global and regional climate systems through the enhanced greenhouse effect. Global climate models predict that anthropogenic forcing will alter both long-term climate parameters and the frequency and magnitude of extreme meteorological events (e.g. heat waves, severe storm events and droughts) (IPCC 2007).

The impacts of pest species invasion are likely to intensify under climate change with increased distribution and abundance of many pest species and increased susceptibility of invaded landscapes (White *et al.* 2008). However, despite acknowledgement of worsening invasive pest species impacts, climate change impact assessments rarely take these into account (Low 2008). As a result, it has been suggested that both the risks and the scale of response required have been critically underestimated (Low 2008).

This paper will focus on the role of risk assessment in decision-making for pest species management under an uncertain future in which key long-term climate variables are expected to change significantly. It will review critical aspects of projected climate change of relevance to both species invasion and invasive pest species management. In addition it will suggest ways in which key understandings of pest species ecology and climate variability can be incorporated into an integrated modelling framework which supports decision-making and strategic adaptive management under uncertainty.

CLIMATE CHANGE

Changes in long-term climate parameters are driven by rising levels of greenhouse gases predominantly associated with the burning of fossil fuels and land clearing (IPCC 2007). For example, atmospheric carbon dioxide levels are currently approaching 390 ppm, almost a 40% increase since the start of the Industrial Revolution. Although year to year variability exists in global surface temperature due to the impact of higher frequency climatic mechanisms (eg ENSO), average global surface temperature has increased overall in response to increases in carbon dioxide and other greenhouse gases associated with anthropogenic emissions. There is scientific consensus that current trends in greenhouse gas concentrations commit the world to an average warming of 2.4 °C (1.4–4.3 °C) above pre-industrial temperatures, in addition to shifts in a range of other climate variables (IPCC 2007).

Climate change in Australia

Changes apparent in the Australian climate include:

- increases in both the average maximum and average minimum temperatures of 0.6ºC and 1.2ºC, respectively, between 1910 to 2004 (Nicholls and Collins 2006);
- increased frequency of record hot days in some regions;
- decreased frequency of cold days and frosts in some regions;
- increased drought intensity; and

- changes in long term rainfall patterns, with north western Australia becoming wetter and southern and eastern areas becoming drier over the last 50-60 years (Australian Academy of Sciences 2010).

Predictions are that the average surface temperature in Australia will increase by up to 1.5°C by 2030 and by 2.2–5.0° C by 2070, and, while important regional variations in impact will remain a factor, average annual rainfall will decrease over much of Australia (IPCC 2007, Australian Academy of Sciences 2010). Overall trends also indicate that Australia's weather will become more extreme, with increased frequency of intense rain, floods, tropical cyclones, droughts and fires (IPCC 2007).

Climate change in Queensland

The average temperature in Queensland over the last decade (2000–2009), the hottest on record, was 0.58 °C higher than the 1961–1990 average (DERM 2010). By 2050, it is projected Queensland can expect an *average* temperature increase of between 1.0 °C and 2.2 °C, with more frequent hot days and warm nights and less frequent cold days and cold nights, along with changes in rainfall distribution, including a potential decrease of three to five per cent in south-east Queensland and up to seven per cent in central Queensland (DERM 2010). Additional changes projected include increased evaporation, longer dryer periods interrupted by more intense rainfall events and flooding, and an increase in the number of severe tropical cyclones (DERM 2010).

Climate variability in eastern Australia

Eastern Australia already experiences significant inter-annual variability in rainfall and primary productivity, due largely to the influence of the El Niño-Southern Oscillation or ENSO (Stone *et al.* 1996). However, models which investigate the effect of global warming on the ENSO phenomenon indicate significant uncertainty in terms of predicted ENSO dynamics under climate change, contributing to considerable variation between models in predicted seasonal outcomes for eastern Australia (Latif and Keenlyside 2008), and potentially increased risk in managing to mitigate ecological and economic consequences. Suppiah *et al.* (2007) suggest a method for identifying more appropriate climate model selection and, thus, providing more useful and appropriate modelled projection outputs of relevance to Australian needs.

INVASIVE SPECIES RESPONSES TO CHANGING CLIMATIC CONDITIONS

Climate change is likely to favour invasive species (Low 2008). Such species are typically successful and abundant due to their broad tolerance of climatic conditions and their capacity for dispersal, hence potential for rapid range shifts (Rejmanek & Richardson 1996, Hellmann *et al.* 2008). These traits are likely to enhance the continued success of invasive species under climate change (Dukes and Mooney 2000). Altered climatic conditions may influence invasion success in a variety of ways and at different stages along the 'invasion pathway' from introduction to management (Hellmann *et al.* 2008). This may occur through changes in the mechanisms associated with introduction and establishment of novel species, changes in the impacts and distributions of existing species, and changes in pest species responses to management strategies (Hellmann *et al.* 2008). However, while it is likely that the spread and impact of invasive species for biodiversity will change under climate change, these changes will be complex and outcomes difficult to predict (Low 2008).

Uncertainties associated with invasive species responses to climate change

Species responses to changing environmental conditions will depend on the nature of climate shifts, species' ecological tolerances to different environmental conditions (especially temperature and moisture extremes), changes in inter and intra-specific interactions, and feedbacks to population and ecological processes.

Opportunity for escape and establishment

The role of extreme events in driving biological invasions is well established. Ecosystems are more vulnerable to invasion when disturbed (Hobbs 1991; Hobbs and Huenneke 1992), and events such as fire, flooding, livestock grazing, and mechanical disturbance provide new opportunities for species which are well-adapted for colonisation and spread (Low 2008).

Extreme meteorological events such as tropical cyclones can play a major role in exotic invasions which is likely to be exacerbated by an increase in their frequency and intensity (Low 2008). As an example, five species of deer which escaped from a deer farm at Babinda during Cyclone Larry in 2006 continue to pose a serious risk to rainforest management in the Wet Tropics World Heritage Area in north Queensland (Kaufman 2006). Further escapes can be expected after future extreme events. Of particular concern are exotic fish in outdoor ponds (Low 2008, 2011).

Changes in species distribution

The ranges and population densities of many invasive species are also predicted to change as climate changes (Low 2008, 2011). Many pest species are expected to expand their geographical range in a warmer climate due to a reduction in cold-temperature constraints; however, this may be countered by hydrological constraints imposed by increased evaporation and altered precipitation patterns (Hellmann *et al.* 2008). It is also likely that the relative abundance of many invasive species will change. Invasive species may respond to increased productivity (due to CO_2 fertilisation) and disturbance (due to an increase in the frequency and intensity of extreme events) in invaded landscapes. Changes in the intensity of intra- and inter-specific interactions may also act to release species from current limits imposed by competition or topdown control (Hellmann *et al.* 2008).

Changes in the range and abundance of invasive species, and their interactions within invaded ecosystems, are likely to alter the ecological and economic impact of invasive species in both natural and production landscapes (Hellmann *et al.* 2008). However, detailed understanding on which to base predictions is currently lacking as few studies have investigated such issues (Hellmann *et al.* 2008).

Use of climate refugia

It is expected that local scale refugia, in which the effects of climate change are moderated to some extent, will provide a level of temporal and spatial protection for native species from temperature and hydrological extremes. However, it is equally likely that these spaces will also be exploited, and potentially monopolized, by invasive species (Low 2011). Refugia may act to enable pest species to persist in environments during adverse conditions, and provide a source population from which they can disperse when conditions improve (Reardon-Smith, pers. obs.).

Microevolution

Invasive species with short life cycles may undergo rapid micro-evolution in new locations, enabling them to escape previous climatic and dispersal limitations (Phillips *et al.* 2006, Urban *et al.* 2007, Xu *et al.* 2009). This may enable them to invade regions exhibiting a wider range of conditions than their native range (Urban *et al.* 2007, Xu *et al.* 2009), and suggests that bioclimatic mapping of expected invasion extent of pest species, based on environmental conditions from existing distributions, may be somewhat unreliable (Broennimann *et al.* 2007).

STRATEGISING INVASIVE SPECIES MANAGEMENT UNDER UNCERTAINTY

Low (2008) makes the observation that the future is likely to be familiar in many respects, with significant year-to-year climatic variability, floods, droughts and fires. However, just as pest species responses to changing climatic conditions and their impacts on ecological and production systems may vary significantly, so may the ongoing effectiveness of existing pest management strategies. Consequently, there is a critical need to evaluate and modify the objectives and strategies of pest species management in view of climate change projections, and for monitoring and assessment of pest species responses to environmental change and management at local and regional scales.

Adaptive management approaches (Walters and Holling 1990), which take an experimental (hypothesis-testing) approach to pest species management, should be a critical component of pest management under uncertainty. Event-centred research aimed at identifying potential tipping points (or critical thresholds) in relation to significant meteorological events will support improved risk assessment and decision-making. In addition, research will be required to address the many current knowledge gaps about climate change impacts, including uncertainties about the climatic tolerances of species and their adaptive capacity, biotic interactions under climate change, human responses, management possibilities and 'wild card' (Low 2011).

Early intervention

Control of invasive species is most likely to be successful where control measures are implemented at an early stage in the invasion process (Park 2004). This is especially so in novel and changing environments (Park 2004, Hellmann *et al.* 2008). It is possible that species already introduced into Australia, but not currently invasive, may become so with altered climatic conditions. Early detection of these species will require broad-based monitoring, followed by rapid decisive coordinated action (Park 2004, Hellmann *et al.* 2008). Delaying action is likely to result in increased abundance and extent of infestation, and increased costs and environmental impact, along with reduced likelihood of successful control (Park 2004).

Potential for maladaptation

Efforts to increase landscape connectivity to enhance native species redistributions under climate change may be counter-productive, promoting the spread of invasive pest species unless these can be effectively managed in these locations (Puth and Allen 2005, Burgman *et al.* 2007, Hellmann *et al.* 2008).

Human behaviour

Human behaviour can play an important role at critical times in relation to pest species invasions. Land managers coping with drought or flooding are less likely to practise good pest control. For example, several pest animal species survived extended drought conditions in New South Wales in higher numbers than expected due to poor levels of control by drought-stressed farmers (West and Saunders 2006). This is counter-intuitive as controlling pest species is likely to be significantly more cost-effective during drought when populations are concentrated in more localised areas with persistent feed and water, and their capacity for recovery is reduced (Edwards *et al.* 2004).

Predictive modelling

While there is considerable uncertainty around how climate change will play out at the local scale, and how it will interact with ecological processes such as species invasions, both biological response and environmental and societal risk are broadly predictable (Hellmann *et al.* 2008). While management under certain circumstances may require detailed process-based understanding of the direction and magnitude of response and of any possible feedbacks, probabalistic modelling approaches, such as Bayesian Belief networks (BBNs), are increasingly used to provide a valuable adjunct to adaptive management programs under uncertainty (Pollino *et al.* 2006, Liedloff and Smith 2010).

BBNs provide a framework which facilitates the synthesis of current knowledge from a range of data types, including expert opinion. They can be used to 'test' response to different environmental scenarios and the outcomes of alternative management approaches (hypotheses) prior to their implementation (Liedloff and Smith 2010), thereby facilitating cost-effective on-ground invasive species management. As such, they have potential to provide valuable support for decision making in adaptive management contexts. The BBN modelling process also provides a mechanism for identifying key knowledge gaps to better target research, and models are updatable as new knowledge is gained (Pollino *et al.* 2006, Howes *et al.* 2010).

Seasonal climate forecasting and decision-making

ENSO has a significant influence on inter-annual rainfall variability and is therefore a key factor in seasonal forecasting systems for Australia (Stone *et al.* 1996). Climate scenario-based models which integrate invasion and climate change biology and seasonal ENSO forecasts provide a promising approach to developing decision-support tools to predict the outcomes of different management actions, and provide an analysis of the level of risk (or uncertainty) associated with these. Such models would provide increased capability to adapt pest species management to changing environmental conditions (Hellmann *et al.* 2008). For example, modelling to predict invasive species response to management under variable environmental conditions associated with climate change could be used to identify key opportunities for management which would contribute significantly to effective pest species control (Edwards *et al.* 2004).

CONCLUSIONS

Clearly, there is a high level of uncertainty associated with assessing the impact of climate change on invasive pest animal species in Queensland, and therefore in planning for cost-effective pest management into the future. Predictive modelling frameworks which enable the integration of climate forecasts and pest species ecology are likely to provide a strong basis for decision-making under uncertainty. Such models will support an adaptive management approach in which decisions can be made within the context of changing environmental conditions; however, this approach will also need to be supported by flexible investment strategies which enable timely (adaptive) management responses at critical periods.

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