Study of climate change and field research in zoology: are they compatible with research student training programs?

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ABSTRACT

Biological diversity in Australia has been dwindling, even without the full onslaught of climate change with the anticipated decrease in numbers of species, communities and effects on associated ecosystems. This makes the impacts of climate change attractive for students undertaking research training in field biology in undergraduate and graduate zoology programs. The projects undertaken by such students are, of necessity, short-term and typically vary between several months and two years of field work. In this paper we consider if such projects are compatible with studying the effects of climate change on Australian native fauna. We conclude that there are limited opportunities for explicit outcomes; however, the research is valuable in a broader context of underpinning longer term research.

Key words: global warming, graduate projects, animal research, study of biodiversity loss, climate change impacts, developing research projects

Introduction

Biological diversity in Australia has been dwindling, even ahead of the full onslaught of climate change. Some 90 species are currently identified as being at risk and one-third of these are listed as 'endangered'. This represents approximately one in six of the species with sufficient data to determine their status; however, for most unlisted species the information required for classification of their status is unavailable (CANA, undated a). Climate change, defined as:

> *…variation in either the mean state of the climate or in its variability, persisting for an extended period, typically decades or longer. It encompasses temperature increase (global warming), sea-level rise, changes in precipitation patterns and increased frequencies of extreme events. Each of these phenomena can impact on biological diversity*

is predicted to exacerbate the threats to biological diversity (biodiversity) (CANA, undated b).

Climate change has indeed often been described as one of the major threats to biodiversity globally (Keppelle *et al.* 1999; McCarty, 2001; Hilbert *et al.* 2007, Dupont *et al.*, 2010; Kroeker *et al.*, 2010; Ross 2011). In parallel with the rapid increase in average global surface temperature over the last century, the observations and predictions of its impacts on species (e.g., shifts in altitudinal gradients, extinctions) have been accumulating (e.g., McCarty, 2001; Shoo *et al.*, 2005a; Hilbert *et al.*, 2007). For example, Shoo *et al.*, (2005a) forecasted that the Australian tropical rainforest birds would be greatly affected, even under the most conservative of their modeling scenarios. At mid-range warming predictions, they forecast that changes in total population size could result in 74% of this bird fauna becoming threatened, and 26 species critically endangered within 100 years. Even under very conservative climate change predictions, butterflies, a group that typically have a wide geographic range in comparison to many other taxa, are considered vulnerable to climate change. Under the most conservative modeling scenario of Beaumont and Hughes (2002), with a temperature change of 0.8 and 1.4 °C, the range of 88% of the species they investigated would contract. Their most extreme, yet moderate temperature change scenario, 2.1 - 3.9 °C, would result in a range decrease in 92% of these butterfly species. A retraction in range of at least 83% species would be by, at least, 50%. In coastal habitats, 'coastal squeeze' (*cf.* Adam 2010) may impact on endangered ecological saltmarsh communities. Any landward migration of saltmarsh habitat and their macroinvertebrate fauna may not be possible if the adjacent terrestrial environments are already anthropogenically impacted or modified (Ross *et al.*, 2009). In the marine environment, evidence of widespread degradation is demonstrated by coral bleaching, and by 2002 it was estimated that 30% of the world's coral reefs were already seriously degraded (Wilkinson 2002). Such bleaching has resulted in rapid changes to community structure due to increased temperature, with a decline in abundance of the primary reef builders (scleractinian corals) and associated predicted changes in community composition of the remaining corals (Munday 2004) and associated fauna, such as fish (Munday *et al.*, 2009).

Pp 169 - 174 in *Wildlife and Climate Change: towards robust conservation strategies for Australian fauna*, edited by Daniel Lunney and Pat Hutchings, 2012. Royal Zoological Society of NSW, Mosman, NSW, Australia.

However, forecasts of future climate change are frequently based on the current known status of these fauna and this may be an underestimate of the real impact faced by global warming. For example, in 2001, McCarty suggested that climate change was no longer a 'looming conservation problem', but that there was already a growing body of evidence that the issue was a current threat to species and ecosystems. Hughes (2003) presented evidence that supported this supposition. She reported that the warming of the earth's surface over the last century was consistent with global climate change and suggested that it is probable that the rate and duration of warming is greater than at any time during the last 1000 years. There is substantial evidence to support this view. For example, in 2001, the Intergovernmental Panel on Climate Change (IPCC 2001) declared that most of the warming of the past 50 years was likely due to increases in atmospheric greenhouse gas concentrations and that this warming had already had significant impacts on species and their ecosystems (see also e.g., Parmesan and Yohe 2003; Parmesan 2006). However, marine habitats are also likely to be affected by the other climate change issue - ocean acidification. Ocean acidification and the synergistic impact of increased temperature threaten the biodiversity of marine organisms and habitats. The ocean is a major sink for CO_2 sequestration, storing nearly a third of all anthropogenically generated CO_2 (Raven and Johnston, 1991; Sabine *et al*., 2004), producing carbonic acid through the dissolution of CO_2 in ocean waters, and producing H^+ and carbonate ions which lower pH (Hoegh-Guldberg *et al*., 2007; Doney *et al*., 2009). Already a decrease of 0.1 units of pH in ocean surface waters has occurred since pre-industrial times (Royal Society 2005; Hoegh-Guldberg *et al*., 2007) and it is anticipated that this will fall by 0.4 units by the end of the century. The evidence therefore indicates that global warming and ocean acidification is no longer a hypothesis, but a reality. The problem therefore is not to mitigate the impact of climate change on biodiversity, both terrestrial and aquatic, but to strive to minimise further loss and find adaptive solutions which will ameliorate climate change impacts.

The identification and ability to overcome such effects due to global warming are complicated by other anthropogenic impacts that typically exacerbate the loss of biodiversity at its multiple levels (gene, species, ecosystem). Identification of the effects is even more complicated when it is considered that the impacts of global climate change may have a range of different impacts, both direct and indirect (McCarty 2001; Walther *et al*., 2002; Parmesan 2006). These impacts may be unique to individual genetic sequences, elicit a different physiological and/or behavioral response in different species, or may detrimentally impact species' habitats by changing the structure of ecosystems and interactions among species. Such impacts may be varied (e.g., unique, additive, synergistic, antagonistic), and while typically considered detrimental, at some level of organization they may be beneficial, at least, at some spatial and/or temporal scales (Schwanz and Janzen, 2008; Gutowska *et al*., 2008). An additional complication in identifying climate change induced effects due to current climatic trends is that they may be masked by non-climatic influences that could dominate local, short-term biological changes (Parmesan and Yohe 2003). Additionally, several attributes of the Australian landscape and its species' biology may even further exacerbate the more broadly accepted impacts of climate change. These include:

- Generally low relief and, therefore, a lack of opportunity for altitudinal migration of species as climate zones move;
- Low and substantial variation in precipitation among years, with most of the continent's inland tending to aridity;
- Widespread, ongoing degradation and loss of habitats (aquatic, terrestrial) with resulting extensive fragmentation, and these remnants are typically degraded due to invasive weeds and pests, together with additional development pressures from human activities; and
- The high proportion of endemic species, flora and fauna, with typically narrow geographic and climatic ranges.

Hilbert *et al.* (2007) further suggested that there was also still great uncertainty about the effects of regional climate change and the potential response of species and ecosystems. They suggested another inhibitor was the limitations on the ability to measure, and even predict, the result of potential impacts on specific species or ecosystems (few have considered the genetic consequences of change; however see e.g., Bradshaw and Holzapfel 2006; Gienapp *et al*., 2008; Visser 2008).

One major issue in studying such outcomes is that the expression of climate change in animal species and/or communities is varied (e.g., ecosystem restructuring, irreparable change or loss; physiological effects; relationships and behaviour; changes in body size; species distribution; development and genetic change; shifts in the timing of events [e.g., breeding, migration], and altitudinal shifts in range). For example, environmental warming tends to result in early arrival of birds that undertake short-term migration early in the season. In contrast, late season, long-distance migrants are much more variable in their response to global warming, while many do not appear to have changed their arrival time at their destination. However, discerning such variability is complicated by natural fluctuations in the numbers of many species (Walther *et al*., 2002) and in variability across geographic range. Similarly, a study of the barnacle *Semibalanus balanoides* found that below a critical temperature, pH had a significant effect on the population only in the southern end of its range, but above this critical temperature (13.18°C), surface sea water temperature had an overriding influence (Findlay *et al*., 2010).

To identify many of these key indicators of the impact of climate change (e.g., disruption of ecosystems, changes in body size, species distribution, shifts in timing of events, altitudinal shifts in species range), of necessity, requires extensive, on-going longitudinal field studies to elucidate, with a substantial historical component that (preferably) dates to pre-anthropogenic climate warming. It has been suggested (Parmesan and Yohe 2003) that to overcome such issues requires the researcher to seek to identify systematic trends across diverse species and geographic regions. Such comprehensive datasets are more commonly available in the terrestrial rather than marine habitats, and far more common from Northern Hemisphere than in Australian systems. For example, changes in bird populations are available for 'numerous' bird species for the last 30-60 years in the United Kingdom (Walther *et al.*, 2002), whereas there are few such databases in Australia (although see e.g., Bradley *et al.*, 1991; Recher, 1997; Wood and Recher, 2004), and they are virtually missing for marine environments (Underwood, 1997).

Despite the exceptions, the lack of long-term databases for most Australian species, and the complexities and difficulties of zoological studies associated with climate change, it is a critical area of study to underpin management of biodiversity with the longer term warming of the environment. Much of this research will be undertaken by research students (see e.g. Shea, 1993, for example, from herpetology) in courses that require the research component (from start to submission) to extend from a few months to three years. In reality, with the pressure to complete a Doctor of Philosophy (PhD - the most extensive student research program) on time, the field component may be restricted to two seasons of fieldwork. This timeframe is typically not conducive to the elucidation of climate change impacts, where the aim is to measure a response over time of the student's chosen taxa. However, such studies may contribute significantly to the overall knowledge of the target species, community and/ or ecosystem. In this paper we address some of the issues associated with field studies for students undertaking research training with a project focused on the impacts of climate change on free ranging, native fauna.

Potential projects for graduate students

The juxtaposition of the need for long-term studies to underpin the exploration of the impacts of climate change (Parmesan and Yohe 2003), and the short-term nature of student research and research funding bodies add a layer of complexity to studying the impacts of climate change on any animal species. This complexity is exacerbated by the lack of information on the bioclimate envelope of many species (Araújo and Rahbek, 2006). In addition, there are often limited data on even the response to naturally occurring climatic fluctuations and/or the confounding effects of other anthropogenic influences (e.g., urbanisation, habitat fragmentation, river regulation) on Australian native fauna and their associated ecosystems. To even identify the potential impacts of climate change on native species in the Australian environment therefore requires studies that span the biology of animal species (phenology), their relationship with their environment (autecology), and the ecological interrelationships among communities of organisms (synecology) across several generations. This lack of comprehensive data provides students with a multitude of project options that would have the potential to make direct and/or indirect contributions to the study of the impact of climate change by extending knowledge of the target species/community. However, they may, of necessity, be restricted to working with hypotheses and research questions that are testable on short-term datasets and only secondarily provide input for climate change research, for example, by contributing to datasets associated with predictions of the impact of climate change (*cf*., Thomas *et al*., 2004; Elith *et al*., 2006). An alternative is to focus research on building on datasets that have been developed over a long period of time (e.g., Recher *et al.*, 2009; Lunney, 1987; Dickman *et al*., 2001; Mahon *et al*., 1998).

Evidence that there have already been shifts in the distribution of taxa in response to climate change is well documented worldwide across a wide range of habitats from tropical marine systems to polar terrestrial regions, spanning a range of ecosystems (e.g., Walther *et al*., 2002; Parmesan and Yohe, 2003; Root *et al*., 2003; Perry *et al*., 2005). Research projects that focus on gathering data on species, particularly those that are poorly described, have the potential, therefore, to underpin monitoring of shifts in their attributes in response to climate change. Findings of studies of broadly distributed species that span gradients - altitudinal, latitudinal and/or longitudinal would be expected to be particularly useful to support such predictions (e.g., Shoo *et al*., 2005a, 2006). Species in areas of particular interest are those where the range extension has the potential for restructuring of ecosystems due to competition (predation, prey, competition) with the species' dispersal. This tends to occur when the leading edge of the taxon expands into new territory as climatic conditions change, thus invading the lagging edge of the range of another taxon (or taxa) and they interact. This is predicted to be of most concern with the southward biome shift towards the pole (for Australia) and upwards in elevation. Developing, or improving knowledge of a species that would enable prediction of its ability to inhabit the physical environment created with climate shift, would enable better predictions to be made of the potential of the species to maintain viable populations (see e.g., Matthews *et al*., 2012). It is within this area that short-term projects required by students undertaking research training would comfortably fit and allow for the testing of predictions for how populations might be impacted by climate change and ocean acidification in estuarine and marine habitats (Findlay *et al*., 2010).

A potentially valuable approach to underpinning predictions is to study the target species in periods of extreme conditions. However, planning such a project is fraught with difficulties because of the expectation of providing graduate students with achievable projects within a strict timeframe. In circumstances of extremes, there may also be issues with ethical conduct of research, if anything other than observation were to be attempted. This is due to the need to avoid additional stress to animals while restrained (e.g., trapping, tagging). Incidental observations in the field due to unpredicted extremes may, however, prove to a valuable adjunct to knowledge of impacts due to climate change. For example, the primary determinant of koala *Phascolarctos cinereus* health is habitat quality (Moore and Foley 2000) and they are considered specialised folivore of *Eucalptus* spp. (Martin and Handasyde 1999). However, some koalas released into the eucalypt woodland of Brisbane Forest Park died as a result of subsequent heatwave conditions. Those that survived abandoned the eucalypt woodland and moved down catchment to the bank of the watercourse, where they sheltered in dense vegetation of non-eucalypt species, predominantly *Melaleuca* spp., until the heatwave dissipated (J. Howard, pers. comm.). Loss of this habitat would not have been predicted to have affected the local population of koalas as a result of climate change. Under such circumstances, the loss of koalas as a result of extreme weather conditions soon after release would (probably) not have been attributed to habitat loss.

Other environments would potentially provide more direct evidence of the effect of climate change. For example, evidence from field studies on the impact of naturally occurring elevations in $CO_{2,}$ such as produced by volcanic CO_2 vents in shallow coastal waters off Ischia in Italy and Papua New Guinea, would allow measures of the impact on communities using a natural pH gradient. However, such field-based studies are rare and generally completed by research teams in isolated areas with high level of resources, which can combine student projects, but these form an exception rather than a rule (Hall-Spencer *et al*., 2008; Fabricius *et al*., 2011).

Many phenological studies will, however, provide baseline data in parallel with testing hypotheses set up to provide short-term research outcomes or, if sufficient data exist, contribute to studies of responses of these species to environmental change. For example, there is substantial evidence that annual recurring lifecycle events may be sensitive to climate change. Such responses have the potential to disrupt the function of ecosystems by impacting on trophic interactions, for example, by disrupting food-web structures. Edwards and Richardson (2004) observed this to occur in response to climate change among the marine plankton of the North Sea. They found differential changes throughout the pelagic community that resulted in a mismatch in tropic levels and functional groups. They predicted that these changes could ultimately lead to ecosystem changes.

There is, however, substantial evidence that annual recurring lifecycle events are sensitive to climate change (Edwards and Richardson, 2004). Changes, such as shifts in timing of migration, breeding, sex ratio changes in species with temperature dependent sex determination, all provide opportunities for graduate research projects. For example, it is likely that species with temperature-dependent sex determination (TSD) will not be able to evolve sufficiently rapidly to counteract negative outcomes due to climate change. The breeding phenology of turtles with such dependence on temperature for sex determination has been shown to be affected by climate warming (Schwanz and Jansen 2008). A study of the response of 59 species of fish where TSD has been (at least) implicitly claimed, showed that in fish with TSD, the sex ratio changed in response to increased temperature at just 1-2°C. In marine and freshwater species, the sex ratio of fish became male-based. For many of the species determined to have sex chromosomes, there were also shifts in sex ratio with increased temperature (Ospoina-Álvarex and Piferrer 2008). In marine environments, in areas of natural upwelling, such as outlined in Hall-Spencer *et al.* (2008) and Fabricius *et al.* (2011), there may be changes in sex ratios which impact on community structure. Changes in migration and timing of breeding also provide insights into the impacts of climate change on taxa. Birds are particularly amenable to this type of study (see e.g., Walther *et al*., 2002).

Conclusions

The development and/or consolidation of study sites as observatories for the long term, intensive study in areas known to be most impacted by climate change (e.g., paired sites at high and low altitude), would encourage a broader understanding of the life cycle of species and communities (spatially and temporally) in strategic areas. However, studies of climate change should not be concentrated in these sites. While developing a superior knowledge of individual 'observatories' is critical to the understanding of ecosystems, there is also a continued need for rigorous research on the broadest range of species and environments across Australia. Since all field studies on native species and their communities have the potential to enhance our understanding of the impacts of climate change on the Australian environment, funding should encourage studies of quality, and not aim at a focal area ('observatory') or species of a particular status (e.g., threatened species). However, while enhancing knowledge of species/communities, their real value to the understanding of climate change will typically be in the provision of data to enhance the modelling, such as that advocated by Parmesan and Yohe (2003) for on-going longitudinal field studies to elucidate the impacts of climate warning.

As with the terrestrial environment, in the marine field there are opportunities for students to complete field-based climate change research, which aim to measure a response over time in the period of a graduate training program. Many studies have been completed in the laboratory and then extrapolated to the field. It is unknown, however, whether this is problematic, because results from the laboratory are not necessarily replicable in the field (either marine or terrestrial) and caution is needed with translating between these two contexts because of unforeseen consequences (Ross *et al*., 2012). This mismatch in expectations is also reflected in a mismatch of the short-term research needs of enterprise universities and institutions, which require outcomes with the longer-term timeframe over which climate change impacts need to be measured.

We conclude that although there are opportunities for students undertaking research training in wildlife field zoology, which aim to measure a response to climate change over time to provide a contribution that will elucidate the impacts of climate change on Australian native fauna, they may be limited because of the timeframe of an undergraduate and postgraduate research degree. Unless students have the unique opportunity to work in selected areas (e.g., the natural CO_2 gradients of neighbouring Papua New Guinea), their contribution to climate change studies typically will be to provide baseline data to strengthen the models, or in mathematical modelling of variables to predict anticipated climate change. If the later is the way forward, then there needs to be considerably more emphasis on the mathematical modelling and development of quantitative skills and opportunities in undergraduate biology degree programs

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