victorian centre for climate change adaptation research

Final report

Use of climate science in adaptation planning and decision making

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Contents

The primary foci of this fellowship

- investigate the way that long-term "paleo" environmental perspectives on climate extremes and abrupt change might inform climate adaptation efforts in Australia, and especially Victoria
- compare perspectives and experiences from SW North America against those of southern Australia, particularly with respect to how climate science can be optimized for use in policy and planning, including by water managers, wildfire and other land managers, as well as those at the climate-energy-water-land nexus,
- inform best practices for the consideration of how long-term climate information might be used to better inform regional planning,
- contribute to both scholarly advances and broader outcomes that will benefit decision-makers and motivate interactions with stakeholders in Victoria and beyond,
- build a foundation for longer-term collaborations with colleagues in Australia, and for building collaborative partnerships between the United States and Australia.

Key findings and implications for Victoria

A. Interactions with a range of stakeholders in Victoria, as well as colleagues in universities, CSIRO, the Australian Bureau of Meteorology and the Australian federal office of the chief scientist, indicated that hydroclimate extremes (i.e., droughts and floods) are top-level concerns. Collaborations were developed and research carried out that reveal that *current state-of-the-art climate models and assessments all underestimate the risk of multidecadal "megadrought" in the State of Victoria, and that there is a substantial risk of future droughts much longer and more severe than any of the last 150 years.*

B. *Climate change significantly elevates the risk of future drought in Victoria, but even without substantial climate change, the risk of multidecadal drought is significant.*

C. *It is likely thus a no-regrets strategy to prepare for droughts longer (e.g., muiltidecadal) and more severe than those seen in the last 150 years.*

D. The same paleoenvironmental research indicates that the future could include an abrupt (i.e., with a transition time as quick as five to ten years) transition to multidecadal periods marked by substantially more frequent flooding.

E. There is an expanded array of roles that physical climate scientists now need to play in order to support effective climate adaptation, and examples of these roles now exist.

F. One key goal for physical and social scientists alike is to move beyond the standard "science and communication only" paradigm to embrace working with stakeholders in interdisciplinary teams to create knowledge needed for effective climate adaptation. The latter approach, often dubbed "co-production of knowledge" has already been proven successful in some cases where it has been tried. Other useful models exist.

G. Additional paleoenvironmental data and perspectives inform challenges of biodiversity adaptation under climate change. *These perspectives highlight that more uncertainties and potential surprises exist than generally acknowledged in adaptation planning. The implication is that the growing multitudes of biodiversity adaptation efforts around the globe should all include the provision for error, as well as the flexibility to face unexpected challenges. Failure comes at a high cost given that extinctions are forever.*

1. Introduction

During my six months in Australia, I was able to get to know a large number of colleagues – both in and outside universities, and both in the natural and social sciences. In addition to my primary affiliation with VCCCAR-related university and stakeholder partners, I also was able to develop working collaborations with colleagues with the multi-university ARC Centre of Excellence for Climate System Science, CSIRO, and the Australian Bureau of Meteorology, as well as with a small number of paleoenvironmental scientists at the Universities of Melbourne and Adelaide who were also interested in hydroclimatic variability and abrupt climate change.

During my fellowship, I also had multiple meetings with VCCCAR researchers Jens Zin and Particia Fitzsimons to explore ways in which a climate scientist could help with their stakeholder-oriented project in Gippsland. In the end, it was concluded that the project was not at a stage that would benefit from further interactions between climate scientists and the local stakeholders.

2. Activities

Part of my strategy for developing collaborations was to give lots of seminars and invited talks (ten total in 6 months):

University of Melbourne *(gave seminar - "Abrupt Climate Change: Getting the Message Right on Potential Dangerous Anthropogenic Interference" March 4, 2013)*

Australian Bureau of Meteorology, Melbourne *(gave seminar --"Assessing Future Megadrought Risk" May 29, 2013)*

Australian National University *(gave seminar --"Assessing Future Megadrought Risk" May 16, 2013)*

CSIRO, Aspendale *(gave seminar - "Assessing Future Megadrought Risk" March 26, 2013)*

CSIRO, Canberra *(met with Adaptation Flagship leaders) May 16, 2013*

La Trobe University, Bendigo (*gave evening public lecture – "Changing climate and weather patterns in North America and SE Australia" June 10, 2013)*

Monash University *(gave seminar --"Assessing Future Megadrought Risk" May 31, 2013)*

University of Adelaide *(gave seminar --"Assessing Future Megadrought Risk" June 13, 2013)*

University New South Wales (and also UTS), Sydney (*gave seminar --"Assessing Future Megadrought Risk" June 5, 2013)*

University of Tasmania, Hobart *(gave seminar --"Assessing Future Megadrought Risk" April 30, 2013)*

I also attended seven conferences and workshops; I gave an additional five talks at these:

National Conference of the Australian Meteorological and Oceanographic Society (AMOS), Melbourne *(Invited talk - "The Importance of High-Resolution Paleoclimatic Records for Assessing Future Drought Risk" Feb 11-13, 2013)*

ARC Linkage Project Workshop: 'Narrowing the scatter and assessing the uncertainty of climate change projections of Australian river flows,' Melbourne (no talk given, but this workshop gave me ideas for the Overpeck et al., paleoclimate paper listed below (in prep.)

NCCARF IPCC WG2 Review 1-day Workshop, Melbourne, May 3, 2013

Inner Melbourne Climate Adaptation Network, Meeting on Drought *(Short talk - "Drought ahead for South/SE Australia?" Feb 27, 2013)*

2013 VCCCAR Annual Forum, Geelong *(Keynote talk - "Climate Science and Adaptation" May 13, 2013)*

2013 National Climate Adaptation Conference, Sydney *(Invited Panel Talk "International perspectives on adaptation action" June 24, 2013)*

Australian Bureau of Meteorology Workshop "Development of a Roadmap for Enhanced Drought Monitoring and Prediction Services for Australia," Melbourne *(Invited talk: The US Experience: Applying new science and understanding to deliver improved drought outcomes" June 25, 2013)*

3. Products

By the end of the six-month fellowship period, collaborations had developed to focus on the preparation of ca. seven publications. These papers reflect my VCCCAR focus on climate dynamics (including paleoclimate), climate adaptation, and climate policy:

Overpeck, J.T. (2014). The challenge of biodiversity adaptation under climate change. In: Applied Studies in Climate Adaptation (J.P. Palutikof, S.L. Boulter, J. Barnett, J. & D. Rissik, eds.). Wiley, Oxford (in press).

Donat, Markus et al (Overpeck is co-author) "Extreme Summer Heat during 1930s US Dust Bowl related to Anomalous Atmospheric Flow in Spring." In final preparation – to be submitted to *PNAS*.

Cook, B. and J. Overpeck, The Knowledge Deficit, Coproduction, and the future of the IPCC (tentative title). In final preparation - to be submitted to *PNAS*.

Overpeck, J. and B. Cook, Embrace adaptation and co-production to create more useful IPCC Assessments (tentative title). In preparation - to be submitted to *Nature Climate Change*.

Overpeck, J. and P. Whetton et al. (TBD) The role of the physical climate scientist in supporting climate adaptation (tentative title). In preparation - to be submitted to *Nature Climate Change*.

Overpeck, J. C. Barr, J. Tyler, T. Ault and J. Cole. A paleoclimatic perspective on megadrought risk in Australia (tentative title). In preparation.

Barr, C. J. Tibby et al. (cast of many). Large changes in East Australian hydroclimatic variability and the changing beat of ENSO over the last 7500 years (tentative title). In preparation - to be submitted to *Nature*.

4. Select results

4.1. The challenge of biodiversity conservations under climate change (see appendix for full paper that is now in press)

Managing – and saving – the Earth's biota in the face of rapid large climate change might turn out to be the largest challenge ever faced by humans. The stakes are high and the complexity of the problem immense. Thus far, collaborations between scientists, resource managers and the public are already beginning to grapple with this complexity and to build capability. There is a growing consensus that much more investment in science and practice will be needed to succeed. A key point, however, is that overconfidence in our ability to succeed could easily spell disaster for species and other biodiversity as they become threatened. Many uncertainties remain, and surprises will happen. Poorly understood prospects for future abrupt climate change are one threat, as are potential abrupt social or political changes that could disrupt the expensive and sizable sustained commitments of resources that will be required for successful biodiversity conservation. The growing multitudes of biodiversity adaptation efforts around the globe should all include greater provision for error, as well as the flexibility to face unexpected challenges. Failure comes at a high cost given that extinctions are forever.

4.2. The challenge of multi-decadal "megadrought" (with Cameron Barr, Jonathan Tyler and Julia Cole)

The conventional wisdom is that droughts of the instrumental era are a good indicator of the range of drought that is likely to occur in the future. In the U.S. and a few other regions of the globe that have high-resolution paleoclimatic data, this has been shown to be untrue – longer, more severe droughts have occurred prior to the instrumental era, and could thus happen again. In Australia, the rarity of long tree-ring and other paleoclimatic data have mostly kept the spectre of multi-decadal megadrought off the radar screens of resource managers, the public and politicians. For example, little evidence appears to indicate that water authorities in the state recognise multi-decadal megadrought as a threat to their businesses, or that there has been appropriate engagement with government or academic scientists to alter this misconception.

Another problem is that state-of-the-art climate models do not provide realistic simulations of droughts longer than those of the instrumental record. Recent work by our team in the U.S. (now published) indicates that models indeed have a bias, and underestimate the risk of multi-decadal megadrought in North America. Prior to my visit to Australia, we hypothesized that the same was true for drought prone parts of Australia (e.g., Victoria). One of my VCCCAR Fellowship goals was to test this hypothesis.

Work by - and with - colleagues from the Universities of Melbourne and Adelaide indicates that multi-decadal megadroughts have indeed occurred in the very recent geologic past, and thus are likely to occur again in the future. Our work also shows that state-of-the-art models do indeed underestimate this risk. However, we are able to apply new methods to bias correct model-based assessments of multi-decadal drought risk. We find that the risk of a 20-30-year drought as severe (dry) as the recent Millennum Drought ("Big Dry") is about 20% in the next 100 years, NOT including climate change; and that climate change (warming and drying on average) substantially increases this drought risk. Moreover, even before climate change is factored in, our new results suggest that there is a 10% chance of a 50-year megadrought in Victoria in the next 100 years. Climate change will exacerbate this risk as well if it is allowed to continue.

Our next step is to publish these results in a peer-reviewed journal, but work already published with similar results for southwestern North America and Africa indicate that our Australian results are robust. Once published, we will collaborate with others (e.g., in the Bureau of Meteorology and VCCCAR) to engage stakeholders (e.g., Melbourne Water) in an effort to increase awareness of the megadrought threat, and to assess possible impacts and options. One clear message, however, is that climate change will significantly increase megadrought risk in Victoria; this too must be communicated widely. Although Australia has a no choice when it comes to dealing with natural drought variability (it must), the people of Australia can chose whether to make their drought risk larger or not depending on their climate change policy.

4.3. The knowledge-deficit, co-production and the IPCC (with Brian Cook)

From a draft abstract (Cook and Overpeck): "Scientific knowledge production is based on recognizing and filling knowledge deficits, but for climate adaptation and mitigation, the applicability of this approach is questionable. The Intergovernmental Panel on Climate Change (IPCC) mandate is an example of this type of 'gap filling,' in which the elimination of uncertainties is presumed to enable rational decision making for individuals and rational governance for societies. This *knowledge deficit model*, though, is unsuited to controversial problems with social, cultural, and economic dimensions. An alternative is needed, particularly given the economic, social, and political scale that action on climate change entails. We review the knowledge deficit model and show how it maintains a wedge between those affected and those whose knowledge is required. We then review the emergence of *co-production* to show how natural and social scientists, as well as the IPCC, might more effectively proceed."

We also envision a second "commentary" paper (Overpeck and Cook, e.g., *Nature Climate Change*) designed to provide more tangible ideas to our climate science colleagues on how the IPCC could change to be more effective – mainly by adopting climate change adaptation is the primary focus of Working Groups 1 and 2, and by engaging a wider range of stakeholders in the process.

4.4. The role of the physical climate scientist in supporting climate adaptation (with principal co-author, Penny Whetton, plus anticipated future input from other physical and social scientists from e.g., VCCCAR, CSIRO and the University of Australia)

Climate science is changing fast, with both climate variability and climate change driving the need to develop adaptation capability. This trend is, in turn, driving a need for physical climate scientists to expand their roles. The goal of this work is to draw on extensive experience of those involved in climate adaptation efforts in the U.S. and Australia to provide insight into the expanding roles that need to be served by physical climate scientists in our respective counties and more globally.

The objective of this work is to review the merits of use-inspired climate science and describe the spectrum of activities physical climate scientist can play to support the growing array of climate adaptation efforts around the world. First, *basic research* will remain critical, and it is just as important to stress that climate scientists need not deviate from their basic climate research focus if it is uncomfortable to do so. That said, we strongly urge these colleagues to engage with others doing more use-inspired research in order to improve the potential usability of their own work. Second, many climate scientists already engage in, or rely heavily on, *climate monitoring*. Climate adaptation strategies often rely on being adaptive: making a plan, implementing that plan, monitoring success and changing environmental conditions, and modifying the plan accordingly to be more successful. Thus, the need for environmental monitoring is going to expand rapidly, particularly at the local and regional scales that climate adaptation efforts must operate, and also as the range of variables that requite monitoring (i.e., adaptation-inspired variables) expands.

The third key role for climate scientists to engage in is *climate assessment*. How is climate changing, what are the impacts of this change, how will climate likely change or vary in the future, and what are the implications of this future climate system behaviour? Increasingly, climate assessment is becoming quite interdisciplinary. Examples include the IPCC, the National Climate Assessment of the United States, and various climate assessments in Australia – often at different spatial and political scales. Involvement in climate assessment activities is an excellent way for climate scientists to gain broader perspectives on climate from the perspective of the natural and human systems that are affected by climate.

Most climate scientists already understand the importance of the fourth role – *communication* of knowledge to policymakers, decision makers and society in general. Many public misconceptions would be eliminated if more (all!) climate scientists made a significant commitment to climate communication. In addition to communicating with the media when any science is published, climate scientists should be looking for opportunities to give talks and discuss climate with any civic, religious, workplace or other group that is interested. Start by stating your willingness to talk/discuss on websites, and also by joining or more of the growing number of climate "speaker" facilitation efforts. It is also helpful to contribute to public outlets (e.g., local newspapers) with opinion pieces, letters to the editor, etc. – note that merely stating the science clearly is a laudable goal, avoiding "opinion" is ok if uncomfortable with the concept. The public needs to know where climate science stands, and why adaptation (or mitigation) efforts might be needed.

Education (role number five) comes naturally to most climate scientists, but part of their expanded role is to contribute more broadly to education – primary and secondary schools, as well as university. Informal education efforts are expanding rapidly, and contributing to short courses and other informal opportunities designed for resource managers and the public to learn about climate and climate adaption is an excellent role for climate scientists.

Of course, and increasing number of climate scientists are now engaging in *climate adaptation research and experimental climate services in support of adaptation*. This role benefits from all of the above-mentioned roles, and means becoming more interdisciplinary. Experience suggests that engagement in such interdisciplinary team-oriented research and services can be the fastest way to make climate science useful and used. Moreover, the growing success of such efforts around the world is leading to the *development of operational climate services* in many countries. Both experimental and operational climate services involve meeting real stakeholder need, and both thus require sustained commitment to building and maintaining trusted relationships with the stakeholders, particularly if scientists wish to co-produce knowledge and solutions with stakeholders.

It is important for climate scientists to recognize the broader range of roles that they must – as a community – fill in order to meet stakeholder and society need. At the same time, research and other institutions must recognize that there is a need to remove impediments to broader climate science engagement, and also provide incentives to broadening the roles that climate scientists can play. First, universities and other research institutions must reward not only traditional scholarly activities (e.g., research, papers, citations and teaching), but must increase incentives for greater use-inspired and service activities, even if they result in fewer peer-reviewed published papers. In the U.S., cooperative extension concepts at some land-grant universities are expanding to facilitate the expanding roles of climate science. In both the U.S. and Australia, mission-oriented federal agencies are also encouraging greater use-inspired work, but in some cases, barriers still exist in working directly with stakeholders in a sustained way. The key is that salary and promotion decisions reward use-inspired engagement in climate adaptation efforts just as much as traditional activities are rewarded.

In some settings (e.g., universities), it is easier to obtain funding in your own discipline rather than spending time applying for funding (grant writing) in interdisciplinary areas needed for effective climate adaptation. Interdisciplinary proposals likely have a higher probability of being reviewed by colleagues who only understand parts of a given proposal, and this might be reflected in review quality. People don't like to waste time on proposals that don't get funded, and funding success is often factored into salary, promotion, and tenure decisions. Both universities and funding agencies need to work on ways to remove this disincentive. Possible solutions include making sure proposals are reviewed by teams of colleagues with the individual or collective (e.g., on a review panel) breadth to review interdisciplinary proposals fairly. Experience suggests it might also help to increase award period length to facilitate greater interdisciplinary integration, as well as provide more incentive for writing the proposal. Some universities provide resources to encourage the development of larger interdisciplinary proposals to help offset the difficulties associated with such proposals.

Climate assessments are becoming too large a burden on climate scientist time, and thus are becoming less desirable activities for the high-quality scientists needed for the assessments. Many assessments (e.g., IPCC and US National Climate Assessment) are carried out on a largely voluntary basis (at least for university scientists, where no one is paying salary for this activity), and although there is large professional prestige associated with authorship in some assessments (e.g., the IPCC), others increasingly do not provide the prestige to make involvement worth the volunteered time. Many scientists don't want to do something unless it can be done right, and is of high quality; but quality requires time and effort. Leadership in assessments (e.g., being a IPCC Coordinating Lead

Author) is an *enormous* time sink and requires support staff. Possible solutions include working to limit redundant or too frequent assessment activities. It would also help to provide salary support or other incentive for participation, especially for those carrying out leadership roles. Whereas government scientists can be assigned to work on assessments, university scientists still have to teach and carry out their other usual activities; thus funds or university support to facilitate reduced teaching loads etc. are needed to incentivize participation. Similarly, leadership roles require staff assistance and provision should be made for post-doctoral or research scientist funding to assist assessment leaders; note that some countries (e.g., Norway and Germany) already provide this type of support for IPCC chapter leaders, but others (e.g., the US) do not. Involving post-docs or other early-career scientists to help with assessment also builds needed capacity.

The goal of our paper (in preparation) is to expand on our assessment of what is required from climate scientists to meet growing real-world adaptation need, and what is needed institutionally to encourage climate scientists to pursue these roles. The importance of climate science is only growing.

5. Reflective questions

5.1. "What was new?"

The whole context of Australian hydroclimate was new for me, as was the more widespread assumption (compared to in the US) that climate change was an important challenge to learn about and prepare for. That said, it was quite straightforward to get up to speed on Australian climate and paleoclimate, in part because of the availability of excellent resources (e.g., at the Bureau of Meteorology) and colleagues who were generous in their time and patience. Major new insight for me came as I learned that Australian climate and river systems were both quite similar to those of southwestern North America (both systems are semi-arid and sensitive to changes in westerly stormtracks), but also quite different in their lack of significant seasonal snowpack. I learned that such streamflow in SE Australian watersheds is likely much less sensitive to climate warming than those back in SW North America. That said, before I arrived, I hypothesized that SE Australia (and SW as well) was likely at substantial risk of multidecadal drought like nothing seen in the last 150 years. Evidence collected during my fellowship allowed me to confirm that this hypothesis is likely valid. In Australia, there is much less stakeholder focus on the use of paleoenvironmental data in support of planning and decision-making than in the United States. This creates a significant opportunity to improve resilience to drought and other climate extremes in Australia.

I was also surprised and impressed by the sophistication of CSIRO (Penny Whetton's group) climate change adaptation support services. There is nothing comparable in the US, and I'd like to figure out how to collaborate to create an even better system – e.g., one informed by evaluation of stakeholder outcomes in both countries. This would be a terrific study, and highly usable.

5.2. "What was challenging?"

Whereas colleagues in Australia were uniformly friendly and welcoming, both personally and with respect to inviting collaboration, I did find it challenging to be dropped into an on-going project (see above – the Zinn/ Fitzsimons Gippsland project). I suspect that this type of issue is inherent in joining any team mid-project, and extra care needs to be taken, especially when a visiting fellow has only limited time to get things done. The lesson is that I should have been in contact w/ the project leads well before I arrived to begin discussions and explore feasibility. A good lesson-learned for me.

5.3. "Has your perspective changed?"

There were two main areas where my perspective was changed. The first was when I finally had the chance to analyze some 1000-year+ hydroclimatic reconstructions from SW Victoria, and it dawned on me that it is the *rule* that state-of-the-art climate models underestimate the risk of multi-decadal megadrought and that semi-arid regions of the globe all have a very real risk of such droughts. They happened in very recent geological history, and thus could happen again.

My second big revelation probably should not have been a surprise. But, when I was researching my essay paper for the Palutikof et al., adaptation book (essay attached), I was struck by how expensive biodiversity conservation will be, and how vulnerable sustained biodiversity conservation efforts will be to failure if we let climate change go unchecked because (1) climate change isn't going to stop for centuries, (2) the change will be large, (3) the change will likely include unforeseen surprises and (4) it will be hard to maintain political will for funding over centuries. Thus, I realized that if humans are unable to slow climate change, there will be a very real risk of mass extinction no matter how hard we try to adapt. That said, adaptation efforts are still be worth the effort, because we could develop cost effect ways to remove CO2 from the atmosphere in the future, thus stopping and reversing climate change. Nonetheless, that is a big bet to make, with much at stake.

5.4. "What will you take away?'

I'll take away new knowledge and perspectives, but the best result of my VCCCAR fellowship is the substantial number of new colleagues and collaborations I now have. It will take me some time to get all of the papers that I started during my visit into press, and I hope to build on these and other collaborations started during my term as a VCCCAR Fellow. Moreover, I'm excited about visiting Melbourne on a regular basis and expanding collaborations. Lastly, I hope that we'll be able to build some worthwhile (and enjoyable) bi-national and other international collaborations with the U.S. and Australia at their core.

5.5. "What was the most important point to you?"

The climate challenge is THE challenge of the 21st century, and meeting this challenge via adaptation and mitigation will be difficult. The key point for me is that scholars and stakeholders from both the U.S. and Australia, working together, will be in a better position to meet the climate challenge. Opportunities also exist to export what works in our two nations to the many other areas of the globe with similar (e.g., semi-arid and drought-prone) situations.

5.6. "What might be done differently?"

See 5.2 – should have reached out to VCCCAR Gippsland Project PI's earlier and before I arrived to determine project feasibility. In the beginning of my fellowship, I focused almost exclusively on meeting colleagues on and off campus in Melbourne, leaving me to make time for invited trips to other universities mostly in the last couple months. By then, I also had established collaborations to work on, and thus ran out of time for making meaningful visits with all of the VCCCAR partner universities. I am lucky in that it looks like I will be able to return regularly to Melbourne and pick up where I left off, but I would encourage future fellows to map out their time more systematically early in their fellowship period, or even before the fellowship begins. Of course, "doing it all" would be quite hard if a visit was significantly less than six months. That said, the contacts I was able to make with new colleagues in Australia, and especially in Melbourne, was the best part of the deal.

6. Concluding remarks

Overall, I feel that my VCCCAR Fellowship was a great success. I learned a lot about climate, climate adaptation and the Australian regional context, ranging from climate, climate-impacts, stakeholders, and institutions to specific climate-related issues and politics. I also now feel much more comfortable thinking about the climate of the Southern Hemisphere – that is, my six months in Australia contributed to making my understanding the *global* climate system more sophisticated.

As anticipated, it was also a real benefit for me to learn about how Australia is responding to their climate challenges. Whereas, the U.S. is a little ahead in some areas of climate science, when it comes to climate adaptation, Australia is in the lead (I suspect globally). I hope to keep learning and exchanging perspectives, but also collaborating to build institutional relationships that help human and natural systems of both our countries deal with the growing climate challenge.

As noted above, I'm quite happy with the interdisciplinary science and papers that are resulting from my VCCCAR Fellowship, but it's the wide range of new professional relationships and collaborations that really made my fellowship a success. I'm looking forward to continuing and expanding my interactions with the VCCCAR family!

Appendix

Overpeck, J.T. (2014). The challenge of biodiversity adaptation under climate change. In: Applied Studies in Climate Adaptation (J.P. Palutikof, S.L. Boulter, J. Barnett, J. & D. Rissik, eds.). Wiley, Oxford (in press).

The Challenge of Biodiversity Adaptation under Climate Change

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The Challenge

The risk of major biodiversity loss given continued human-driven climate change is real. Estimates of potential species loss range as high as possibly the Earth's sixth major mass extinction (Barnosky et al., 2011; NRC, 2013), but even though the most recent scientific consensus points to serious extinction risk, a firm estimate of potential species loss still eludes us (Leadley et al., 2010; Settele et al., 2014). And of course, there is more at risk than just the loss of species and diversity; maintaining the evolutionary and genetic flexibility of species to adapt to future stresses, climate and otherwise, is also an important objective (Reed et al., 2011; Hoffmann and Sgro, 2011). Species and their genetic flexibility are the foundation of ecosystems that provide many key services to humans, ranging from cleaning water and air, to providing renewable natural resources, to making up the composition of valued parks and preserves, and much more. There is little doubt that humans have a strong need to avoid major ecosystem damage and biodiversity loss.

A key question for policymakers, conservation managers, and humankind more generally is whether nature itself, or nature assisted by humans, can adapt to some level of climate change?

Fortunately, we know nature by itself can adapt to some level of climate change. Climate has always changed on timescales of years to millions of years (Masson-Delmotte et al., 2013), and the Earth's biota has obviously persisted through much of this change relatively unscathed (Dawson et al., 2011; Settele et al., 2014). However, there have also been times when climate change has contributed to higher than usual extinction rates, ranging all the way up to mass extinction (Barnosky et al., 2011; NRC, 2013; Settele et al., 2014). We also know that most species on Earth have also managed to adapt to ca. 0.9°C global warming since 1901 (and greater change regionally – Hartmann et al., 2013; Settele et al., 2014), but that some species have already been stressed substantially even in the face of this recent climate change – change that could end up being small compared to changes in decades to come (Settele et al., 2014).

So how does the risk of biodiversity loss scale with the magnitude of human greenhouse gas emissions and the resulting global climate change? At present, we know with confidence only that risk goes up with the magnitude of climate change (Settele et al., 2014). Can't we do better and quantify this relationship? Because extinction is forever, what level of extinction risk, and thus climate change, is acceptable? Thus, a more all-encompassing question remains – what level of anthropogenic climate change will trigger unacceptable levels of biodiversity loss?

Unfortunately, even if humankind can decide what constitutes "unacceptable," estimates of how biodiversity loss will scale with future levels of greenhouse gas emissions and global climate change will probably never be secure enough to bet the Earth's biota on – at least not any time soon. The goal of this essay is to highlight why this is true (see also e.g., Stein et al., 2013; Settele et al., 2014), and to encourage great vigilance when assessing all of the serious threats biodiversity might face in any given region. If an over-arching goal is to preclude mass extinction, it would be wise to err on the side of caution and fight more aggressively to reduce the climate change and other threats to biodiversity.

The growing quiver of adaptation tools

The time to debate the value of adaptation is over – it is one of the two primary tools (the other being mitigation of greenhouse gas emissions) for dealing with the effects of climate change and other human stressors that are already threatening biodiversity (e.g., Staudinger et al., 2013; Settele et al., 2014). As a result, adaptation science and implementation are going to be defining human endeavours for the rest of the 21st century and beyond. The good news is that adaptation science has already come a long way (e.g., Dawson et al., 2011; Stein et al., 2013; Settele et al., 2014; and papers that follow in this volume), but the bad news is that much remains to be learned. The quiver of useful adaptations tools is growing, but will it be enough?

The four papers that follow this essay collectively do a nice job of highlighting the science and application of biodiversity adaptation by describing efforts focused on the conservation of a number of species in Australia. Many aspects of biodiversity adaptation are summarized, including the daunting magnitude of the challenge associated with just conserving the focus species alone, and the implications of these papers go far beyond biodiversity conservation in Australia alone. In doing this, the much bigger financial challenge associated with conserving the complete biodiversity of an entire country is put in perspective ('a frightening sum', Garnett et al, 2014), as is the even larger challenge of conserving biodiversity in poorer countries and around the globe. Reading just these four papers makes clear how expensive a successful global biodiversity adaptation effort could become – quite possibly this adaptation effort could become more expensive than transforming the world's energy infrastructure sufficiently to *avoid* major climate change and biodiversity loss.

The following four papers also offer a useful and succinct overview of adaption strategies, including the need to manage both climate and non-climate stresses, acting in the face of significant uncertainty, and embracing continual learning and adaptive management. The case for expanded natural and social science research, as well as more extensive monitoring of the multiple stressors, is made. The inequity of perceived species value also comes through loud and clear – some charismatic species and ecosystems garner attention and investment, while many others are not on the current adaptation radar screen. Concern over this fact is heightened by extensive poorly understood relationships among species, and because many species and other aspects of ecosystems go unstudied and unmonitored. Moreover, the papers highlight the key roles that local to national governance can – and in some cases, must – play if adaptation efforts are to be successful. Collectively, these four papers highlight a challenge that is as complex as it is potentially expensive.

Emerging threats to successful adaptation

Given space, it would be possible to generate a long list of issues that might threaten successful adaptation (e.g., Dawson et al., 2011; Stein et al., 2013; Rudd and Fleishman, 2014; Settele et al., 2014, as well as the papers in this book), and that when combined with the 'forever' aspect of extinction, should be dealt with better than might currently be possible. The list that follows is just a subset of these issues that needs more consideration.

Limits to climate models

A primary climate science concern is that climate models – as good as they now are – do not agree on the magnitude and detail of climate change that might result from a given level of greenhouse gas forcing. Many adaptation efforts use multi-model ensemble averages to anticipate future climate stresses, when ranges and low probability/high risk changes might be just as important to biodiversity adaptation. Moreover, these same state-of-the-art models are not presently able to simulate all aspects of future climate that may be key to some biodiversity conservation efforts. Clever use of multi-model ensembles can provide improved estimates of the range of change that might occur in any given location (e.g., Dominguez et al., 2012; Vano et al., 2014), but some key variables, for example extremes like drought and megadrought, might not be well-simulated by any model (Ault et al., 2013; 2014). Will adaptation strategies fare well if confronted by a drought that is much longer and hotter than ever seen before? Similarly, climate models also seem unable to capture the full range of El Niño and La Niña behaviour that is apparent in instrumental observations (Flato et al., 2014). Even more troubling is the paleoclimatic evidence that the range of ENSO behaviour in the instrumental record was eclipsed by larger, more prolonged ENSO-related extremes in recent Earth history (e.g., Conroy et al., 2008; 2009). As a rule, then, wise adaptation plans will often need to have provision for much larger and longer climatic extremes than have been seen in the instrumental record or in state-of-the-art simulations of climate.

The potential for abrupt change and surprise

Another climate issue is abrupt change. Closely linked with the issue of "climate surprises," there is a whole range of abrupt, tipping point or threshold climate system behaviour that is evident in paleoenvironmental records that is not fully understood, nor proven to be within the capability of our climate models (Overpeck and Cole, 2006; Lenton et al., 2008; NRC, 2013). One increasingly well-known issue is that of abrupt shifts between prolonged wet and dry periods, which is more likely than previously thought (Ault et al., 2013; 2014). Another is the abrupt sea level rise that could take place at rates in excess of 1 m per century if ice sheet collapse accelerates further. This could then drive unprecedented coastal storm impacts (Parris et al., 2012; Church et al., 2013; NRC, 2013). Moreover, many multi-model projections of climate change are presented as if they will be steady and gradual through the coming century and beyond, when in fact they could be characterized by abrupt shifts along the way, particularly at local scales critical for biodiversity conservation (Overpeck and Cole, 2006; Higgins and Scheiter, 2012).

Historical evidence

In some sense, it is comforting that the Earth's biota has dealt with the full range of climate system behaviour in the past, and has persisted. That said, biota in many parts of the globe will soon be confronted by climate unlike any it has ever seen in its evolutionary history (Diffenbaugh and Field, 2013; Settele et al., 2014). Uniquely high temperatures are likely in many places, as are higher rates of climate change than seen in millennia. And, of course, the additional human-related stressors will be uniquely challenging as well: unprecedented atmospheric carbon dioxide concentrations and other air and water pollution, depleted groundwater, fragmented landscapes, invasive species, predation, etc. This means great care must be taken to avoid assuming the past is a good guide for the future in terms of understanding how biota will respond to climate, and in terms of understanding the natural capacity of biota to deal with climate change.

Future human behaviour

As challenging as it may be to improve and compensate for climate model shortcomings, it is probably achievable. For example, careful model-based interdisciplinary scenario planning, coupled with clever use of instrumental and paleoclimatic records (e.g., Ault et al., 2014), might allow conservation managers to bracket the full range of future climate threats. However, biodiversity conservation plans could conflict with other aspects of climate change adaptation and mitigation (e.g., renewable energy or biofuel deployment), and make the complexity of biodiversity conservation planning and implementation more daunting. Moreover, a bigger problem could be the inability to characterise future human behaviour, ranging from estimating future greenhouse gas emissions, to assessing the stability of future governments and their commitments to biodiversity conservation. As the following papers make clear, the cost of biodiversity adaptation on a global scale could be extremely expensive, and of course, it would have to be sustained for decades and longer to be successful. It seems risky to assume that the will to sustain an ever-expanding array of adaptation programs is guaranteed, even if the cost of failure could be the Earth's sixth major mass extinction event.

The bottom line

Managing – and saving – the Earth's biota in the face of rapid large climate change might turn out to be the largest challenge ever faced by humans. The stakes are high and the complexity of the problem immense. Thus far, and as the following chapters of this book attest, collaborations between scientists, resource managers and the public are already beginning to grapple with this complexity and to build capability. These chapters also support the growing consensus (e.g., Dawson et al., 2011; Stein et al., 2013; Settele et al., 2014) that much more investment in science and practice will be needed to succeed. A key point, however, is that overconfidence in our ability to succeed could easily spell disaster for species and other biodiversity as they become threatened. Many uncertainties remain, and surprises will happen. The growing multitudes of biodiversity adaptation efforts around the globe should all include the provision for error, as well as the flexibility to face unexpected challenges. Failure comes at a high cost given that extinctions are forever.

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