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The Australian Museum welcomes the opportunity to contribute to the Parliamentary inquiry on biodiversity and climate change. As an institution with considerable State, National and International biodiversity research capacity and biological collections dating back some 180 years, together with stated strategic priorities relating to understanding the potential impacts of climate change on Australia's biodiversity, the Museum is well-placed to comment on the impacts of this critical threat.

Our submission comprises a short section outlining the Museum's standing with respect to biodiversity and climate change, some general comments that apply to multiple terms of reference and more specific comments in relation to the terms of reference in which we have expertise, viz., terrestrial, marine and freshwater environments. A small number of recommendations are highlighted in the submission.

BACKGROUND AND GENERAL COMMENTS

The Australian Museum is a statutory corporation established under the Australian Museum Trust Act 1975, with a legislative mandate to propagate knowledge about the natural environment of Australia and to increase that knowledge, particularly in the natural sciences of biology, anthropology and geology. It is principally funded by the NSW Government operating within the Department of Trade and Investment, Regional Infrastructure and Services.

The Museum's research strengths include zoology, taxonomy, systematics, molecular genetics, biodiversity, ecology, palaeontology, materials conservation, archaeology, anthropology and geology. Representing the country's first museum, and one of the oldest natural history museums in the world, the Museum holds over 18 million items in its collections including cultural objects and animal, fossil and mineral specimens. With public galleries, collections and research facilities are based in the Sydney CBD, the Museum also includes the Lizard Island Research Station in Queensland – a global centre for coral reef research on the Great Barrier Reef. A considerable amount of the research supported at the Research Station is related to understanding impacts on the Reef.

It is important to appreciate that Australian expertise and research capacity in biodiversity reside largely in the state and territory natural history museums, as there is no national museum of natural history. The state museums are the largest employers of taxonomists (scientists who specialize in the study of biodiversity) in the nation. Beyond 'public good' dimensions, species identification expertise (or taxonomy) plays a vital role in key applied research activities that have enormous economic and social impacts on the nation. Identification of pest species (which are projected to cause increasing impacts on our biodiversity as a result of climate change) is a classic applied example. The direct cost of the main introduced pest species was conservatively estimated by the Australian Bureau of Rural Sciences in 2006 at more than $400m per annum, excluding environmental and social costs. At the same time, Australia's capabilities in this area are in a critical state of decline because of an ageing workforce, highly restricted funding sources and a lack of targeted training programs and tertiary courses to attract new recruits into the discipline. Reversing this loss of taxonomic capacity is essential if we are to understand Australian biodiversity, how it will respond to climate change, what the costs will be to the Australian ecosystems, economy and society, and how we can best ameliorate the effects of climate change on our biodiversity.

While this deficiency in species identification can, in part, be addressed through technological developments such as molecular approaches to species identification (including the relatively recent process called DNA Barcoding), there needs to be an integrative and prioritised approach with appropriate emphasis on education and training in taxonomy to meet the challenge. From a more holistic perspective, we believe there is merit is assessing the full set of capabilities required to better understand the impacts of climate change on biodiversity. This assessment should consider both collaborative, inter-institutional arrangements to amass the critical elements of expertise and technologies required, together with consideration of the skill sets of individual researchers in the field. What expertise should a biodiversity - climate change specialist in the 21st Century possess and what support (training, funding etc) is required to develop this capacity?

Understanding the potential impacts of climate change on biodiversity is a complex challenge, relying heavily on the integration of disparate sets of data together with analytical tools so that the available information can be easily synthesised and translated into forms that are required to input effectively into decision-making. As the Department of Innovation, Industry, Science and Research (DIISR) 2011 Strategic Roadmap for Australian Research Infrastructure (Exposure Draft) recognises, digitisation infrastructure is a critical capability area required to maximise the benefit of Australia's significant investment in biological collections. Online capabilities open up new and innovative approaches for engaging with the worldwide research and end-user communities. The Atlas of Living Australia (ALA), a partnership between CSIRO and the Australian natural history collections community and the Australian Government, is one such initiative that serves as a sound model for building our capacity in this area.

The Australian Museum strongly supports the continued funding of existing integrative platforms such as the ALA, as the benefits of such large-scale multi-faceted initiatives will continue to accrue as the quantity and quality of the content is enhanced.

SPECIFIC AND DETAILED COMMENTS

1. Terrestrial, marine and freshwater biodiversity in Australia and its territories

Terrestrial environments:

The terrestrial environment of Australia and its territories hosts a vast array of biodiversity. Most terrestrial biodiversity (fauna and flora) in Australia and its territories is endemic (ie is locally unique and occurs nowhere else). Many species are extremely localised in distribution (less than a few square kilometres). Some continental areas also highly biodiverse and show exceptionally high endemism, for example the Wet Tropics of northeast Qld, forest/woodlands of south-eastern Australia, south-western Australia, the Kimberley, the Top End and Cape York Peninsula. Australia is the second 'driest continent' after Antarctica, which creates particular problems when climate changes. Hydrophilic or rainforest species are either extremely restricted in distribution (rainforests) or widespread (temporary water bodies) and the diverse and phylogenetically isolated flora & fauna (biota) of the former is particularly susceptible to increased aridity. There is strong evidence in Australia for river valleys, with less rainfall, acting as barriers between rainforest populations, leading to speciation. Australia is also the 'flattest continent' with particularly low altitudes. The unique biotas of our few high altitude areas are especially vulnerable to increased temperature. Island territories such as Christmas Island, Norfolk Island, Lord Howe Island are especially high in unique terrestrial species.

In the widespread arid, semi-arid and generally low rainfall regions of Australia, fire is a major determinant of biological community structure. Climate change has an obvious impact on fire regimes. Climate change also leads to changes in land use by humans and changes in distribution and dominance of exotic species, both of which will have severe impacts on the Australian biota. Many terrestrial species are specialised to particular conditions/habitats, and have highly restricted distributions. These are especially vulnerable to extinction through climate change. However, much terrestrial biodiversity remains undocumented and undescribed. In Australia, only birds and mammals (and to some extent butterflies) are at all well known and even in these groups new species continue to be recognised. This lack of knowledge is exacerbated by a critical shortage of taxonomists, taxonomic research and funding for them.

World Heritage listed rainforests of northeast Queensland are amongst the most biodiverse areas of Australia. Most species occurring in this area are found nowhere else and many of these species (including mammals, birds, reptiles, amphibians, invertebrates) are restricted to areas of high elevation. As the climate warms the suitable environment for these species will shift to higher elevation and so become increasing restricted, isolated, fragmented and then disappear completely. Climate change, even if limited to a 2°C temperature rise, is predicted to result in massive loss of biodiversity in this area (Williams et al. 2006). The same is likely to be true for species in many other ecosystems, including the rainforests of southeast Queensland and northern NSW, as well as the Australian Alps, but these ecosystems are less well studied and understood.

It is not just localised species that are threatened by climate change. The distributions of most species will alter with climate change, often quite dramatically. For example the antilopine wallaroo, an iconic tropical kangaroo, which is currently found in tropical woodland across northern Australia, is predicted to suffer a major range reduction (~90%) to small areas of Cape York Peninsula under a 2°C temperature rise (Ritchie & Bolitho 2008).

Marine environments:

The Australian temperate marine environment has a very high proportion of species that are endemic. As the ocean warms, these species will increasingly be restricted to a smaller portion of Australian waters in the south. Unlike northern hemisphere environments, where coastlines extend well into high latitudes, Australian temperate species cannot migrate along the coastline to cooler high latitude waters. As a result, many Australian endemic marine species will become endangered and some will become extinct. This includes many species of commercial and recreational importance.

Increasing ocean temperature is a major challenge for Australia in the area of biodiversity conservation. This challenge is compounded by a lack of knowledge of the actual biodiversity of much of Australia's marine environment. This is especially true of northern Australia and in the deeper waters of our Exclusive Economic Zone. In addition, scientists are finding that many marine benthic (seabed-dwelling) invertebrates are actually multiple species so there is a serious underestimate of our known biodiversity (Ponder et al. 2002).

Further, there is good evidence that the abundance and number of marine pest species may increase with rising water temperatures (see references in Przeslawski et al 2008). Recognising an animal or plant as a pest soon after its introduction is the key to eliminating or controlling the problem and therefore mitigating impacts. Examples of cost-effective pest eradication programs once populations are established are extremely rare. Despite many decades of intensive effort, no widespread introduced pest animal species has ever been eradicated from mainland Australia, and marine introductions are more complex and logistically challenging given the high degree of connectedness in marine environments, lower visibility and access issues. The economic costs of intervention are generally prohibitive, yet the economic and environmental costs are also enormous.

Accordingly, the Museum recommends a specific recognition of the need to develop the appropriate species identification systems, tools and skills for early marine pest detection. Technologies for rapid species identification, such as DNA Barcoding warrant particular attention.

Freshwater environments:

Amphibians have long been accepted as an indicator or 'corner stone' group of species indicative of environmental health. Around 93% of Australia's 233 amphibian species are endemic (Hero *et al.* 2008; IUCN 2011). The highest amphibian diversity is along the south-east coast of Australia and in the wet tropics of north Queensland. An estimated 22% of Australia's amphibian species are currently threatened, and approximately half of these are thought to be directly threatened by climate change and extreme weather events (IUCN 2011).

Worldwide, amphibians are already responding to climate change. Spawning dates and breeding migrations in a number of amphibian species have already become significantly earlier (Beebee 1995; Gibbs and Breisch 2001). These changes alter the composition and dynamics of communities, with complex and unpredictable outcomes.

A synergistic interaction between temperature change and infectious disease may explain many of the recent population declines disappearances of amphibians globally. Outbreaks of the amphibian disease *chytridiomycosis* have been linked to the extirpation of many frog populations, and in at least some cases, these outbreaks appear to be correlated with climate (Puschendorf *et al.* 2008). For example, around 80% of missing harlequin frog species in Central America vanished in years with warmer than average temperatures (Pounds *et al.* 2006). The likelihood of this correlation occurring by chance is more than one in a thousand (Puschendorf *et al.* 2008).

In Australia, the pattern of decline in amphibian populations shows many parallels with those in the Neotropics. In eastern Queensland at least 14 species have experienced declines in recent decades, with five species disappearing altogether, and others becoming locally extinct at high-elevation sites. The fungus *Batrachochytrium dendrobatidis* has been implicated in most of these declines. In these areas, where *B. dendrobatidis* now appears to be an epidemic, patterns of infection and mortality are consistent with the climate-linked epidemic hypothesis, with amphibian infection levels and mortality highest during cooler months (Berger *et al.* 2004; Retallick *et al.* 2004; McDonald *et al.* 2005; Woodhams and Alford 2005).

Future predictions for amphibians are grim, with 13% to 68% of frog species endemic to Queensland predicted to become extinct under future climate scenarios (Thomas *et al.* 2004). This prediction is based on the effects of changing climatic conditions alone. The true impacts of climate change may be far more complex and potentially detrimental when acting in synergism with disease.

Australian freshwater environments are well recognised as being exposed to substantial threats owing to the aridity of the landscape combined with the increasingly unsustainable usage of water resources, either from mining, agriculture or urban water needs. Although these threats are well understood and recognised in legislation for the surfical waters like lakes and streams, the threats are possibly greater for the diverse and poorly known groundwater and groundwater-dependent ecosystems in Australian aquifers and surface exposures of groundwater such as springs and human-created bores (Boulton et al 2003; Humphreys 2008). Freshwater aquifers support a diverse array of micro-endemic species. While arthropods seem to be best understood now (e.g., isopods, amphipods, ostracods, copepods, dysticid beetles), most major animal groups can be found in groundwater habitats. These will be greatly impacted by changing climate and rainfall patterns and human extraction of groundwater in response to climate change.

2. Connectivity between ecosystems and across landscapes that may contribute to biodiversity conservation.

Terrestrial environments:

During past episodes of natural climate change, natural ecosystems covered the Australian terrestrial landscape and habitats, so species were able to move freely across altitudinal, latitudinal and rainfall gradients to track their favoured environmental conditions. However, human activity over the last 200 years has effectively destroyed natural connectivity throughout much of Australia's terrestrial landscape. This widespread loss and fragmentation of native vegetation will prevent many species from tracking their preferred climatic envelope as it moves under climate change and will increase the magnitude of biodiversity extinction.

It is vital therefore to protect remaining landscape connectivity of natural ecosystems and to enhance and restore connectivity wherever possible along altitudinal, latitudinal and rainfall gradients to build maximum resilience into remaining ecosystems (Heller and Zavaleta 2009).

Marine environments:

Increased ocean temperatures will increase metabolic rates of cold-blooded animals (ie, most marine species). Increased metabolism will increase the requirement for food per unit time. Food may become limiting, and vulnerable life history stages may starve or lose condition making them more vulnerable to disease and predation or unable to reproduce successfully. Increased metabolism will decrease the duration of larval stages, and will likely decrease the geographic scale of population connectivity of marine species (the majority of which have complex life histories including a dispersive larval stage). This will have an significant effect on fisheries and conservation management (for more detail, see Munday et al. 2009).

Recently, Przeslawski et al. (2008) reviewed the effects of climate change on reefal invertebrates (excluding corals), and the synergistic effects: ie, not just increasing water temperatures, but also increasing ocean acidification, increased intensity of storms, sea level rises, increased UV levels, changes in ocean currents, among others. Impacts will be cumulative and may be non-lethal but with significant impacts, for example, reduced fecundity, changes in timing of spawning, reduced rates of calcification, and may result in larvae and juveniles having insufficient food supplies or being more susceptible to predation (reduced skeletal structures), or changing ocean currents will disperse the larvae to unsuitable habitats for settlement.

The timing of elevated water temperatures or storm events is critical. If this occurs during spawning, it may be very damaging, but if occurs at other stages of the life cycle it may have far less impact. There will be winners and losers, with climate change. For most marine invertebrates we have very limited data on the temperatures at which individual species die, and this is particularly true for larvae. It is also important to stress that these impacts of climate change are not uniform along the coast. Modelling by CSIRO clearly suggests that some areas will be more impacted than others. This is illustrated by the patterns of coral bleaching along the Great Barrier Reef. During any bleaching event some reefs are impacted while others not.

3. how climate change impacts on biodiversity may flow on to affect human communities and the economy

Terrestrial environments:

Climate change will impact all Australian terrestrial ecosystems. The degree of species loss and disruption to ecosystem function is unclear but evidence suggests it could be significant. There is likely to be significant impact on ecosystem services which currently benefit human communities and the economy. This includes CO_2 storage, soil stability, pollination, pest control, water and nutrient cycling and pollution amelioration.

Impacts on major tourist destinations will also be severe. There is concern that iconic species for tourism such as the koala will be negatively impacted by elevated CO_2 levels which causes plants to grow more quickly but as a consequence be less nutritious (ie contain more fibre and less protein). This 'CO_2 fertiliser' effect will negatively impact many herbivores but especially those like the koala already feeding on low quality vegetation (http://www.theaustralian.com.au/news/health-science/koalas-at-risk-as-trees-lose-nutrients/story-e6frg8gf-1111115980220). It means they must eat more to survive and is likely to reduce longevity and reproductive rate and as so elevate extinction risk, especially in low density populations or those in marginal habitat.

Terrestrial environments are also threatened by inundation, for example major sea turtle and bird breeding/roosting islands (often low coral cays) which will not only impact these important species but also the tourist industry. The tourism value of other key destinations (such as the Queensland Wet Tropics and Lord Howe Island) where wildlife is a key part of the visitor experience will also be impacted with species loss predicted under climate change.

Marine environments:

Many marine species of commercial and recreational importance will undergo range alterations. Temperate marine species will suffer range reductions, and some will become extinct. The scale of population connectivity will decrease, which will have a strong impact on viability of populations, and upon management of living marine resources including fisheries and marine protected areas.

Repeated bleaching events on reefs, will lead to death of corals and associated invertebrates (Stella et al 2011), resulting in increased rates of bioerosion and loss of reefal substrate and replacement of coral reefs with algal dominated reefs. This will reduce the ability of fringing reefs to protect low-lying coastal communities. Loss of reefs and associated fauna will reduce the value of those reefs both in terms of loss of fisheries but also tourism, as algal dominated reefs have less appeal to tourists.

Sea level rise will impact many nursery areas that are vital for fish and invertebrate populations ie, estuaries, mangrove areas and other wetlands. These will be pushed inland by rising sea levels. In many cases, human development on land means there will be no place for these environments to migrate, and they will be reduced or disappear all together. This will have a major negative impact on both recreational and commercial fisheries as well as on biodiversity in general.

Freshwater environments:

Sea-level rises associated with climate change will also seriously impact many coastal freshwater wetlands through saltwater intrusion and inundation. These freshwater wetlands are highly biodiverse and exceptionally rich environments currently supporting major concentrations of wildlife (eg birds, fish and crocodiles) and particularly in northern Australia are highly significant for the tourist industry (eg, the World Heritage listed wetlands of Kakadu National Park).

4. **strategies to enhance climate change adaptation, including promoting resilience in ecosystems and human communities**

Terrestrial environments:

Resilience in terrestrial ecosystems would be encouraged by reducing impact of current threats including:

- introduced species (cats, foxes, goats, camels, deer, cane toads etc), disease and weeds, as well as preventing the introduction and establishment of additional exotic species, pests and diseases. Current quarantine procedures (involving detection and eradication) are inadequate as recent establishment of invasive pest species such as myrtle rust, Asian honey bee and fire ants, among others, demonstrates. Similarly, weedy species in agriculture and horticulture are recognised as major threats and stressors to native ecosystems.
- changed fire regimes (eg too many too hot fires are currently degrading many terrestrial ecosystems).
- clearing and fragmentation of native vegetation.

Other strategies to increase resilience should include:

- Increasing protected area networks, especially of biodiverse and relatively intact ecosystems in areas of high fertility.
- Encouraging biodiversity conservation on private land, including retaining native vegetation.
- Actively restoring connectivity of habitat and ecosystems across the landscape to allow for natural shift of ecosystems and species as climate change occurs.
- Assisted colonisation (ie active movement of species to areas where their favoured habitat is predicted to be in the future) for species of biological, economic, scientific or cultural importance that will be unable to colonise new suitable areas by themselves because the rate of climate change is too rapid; they are poor disperses; natural migration is blocked by human infrastructure or clearing (Hoegh-Guldberg et al. 2008).
- Building increased genetic resilience (evolutionary potential) into managed wildlife populations to facilitate increased genetic diversity and improved ability to adapt to climate change (Weeks et al 2011). Many current wildlife translocations and supplementation strategies tend to deplete genetic diversity and therefore adaptability (Eldridge 2010).

Marine environments:

Resilience of marine ecosystems can be promoted by reducing other impacts, such as pollution, habitat destruction, and over-exploitation.

Marine protected areas (including extensive no-take zones) are a major means by which resilience can be enhanced. For example, the Great Barrier Reef Marine Park Authority (GBRMPA) has been employing management strategies that improve water quality and reduce overfishing, to minimise potential impacts of climate change.

Bleached reefs are more likely to recover from bleaching if other impacts such as water pollution is high, and conversely, bleached reefs are less likely to recover if water quality is low. The recent GBRMPA Outlook report expands on this view of providing the best environment for corals, and hence the associated fauna to recover.

Further, reducing fishing pressure will maintain the fish herbivores and reduce the likelihood of coral reefs suffering a phase shift and becoming algal dominated reefs.

Freshwater environments:

Wetland desiccation due to climate change is associated with declines in amphibian abundance and biodiversity.

To ameliorate these effects, it may be possible to create suitable refuges in droughts via the use of irrigation systems or creation of artificial shelter sites (possible local-scale strategies outlined in Shoo *et al.* 2011).

Resilience in amphibian populations may be promoted by the enhancement or restoration of breeding sites or core habitat.

5. mechanisms to promote the sustainable use of natural resources and ecosystem services in a changing climate

The Museum notes that many of the points made under the previous terms of reference also apply to this one, but makes the following additional comments regarding marine environments:

- Marine protected areas (including extensive no-take zones) are a major means by which resilience and sustainability can be enhanced.
- Research on the phylogeny, life history, connectivity and ecology of marine species will enable us to better understand the way populations of marine animals function, and therefore to manage them more effectively for sustainability and climate change impact.

Museums can play an important role through the changes in distribution patterns that can be examined using their collections data. Recently, Falkner et al (in review) reviewed distributions of marine invertebrates to determine what changes in species distributions could be assigned to climate change, and also if museum records could document changes in distribution patterns. Limited support was found, but this may reflect sampling deficiencies.

We recommend that sites along the coast are selected (especially intertidal and shallow subtidal) and suites of taxonomically well known, common marine invertebrate species which can easily be identified, be monitored every 3 to 5years to determine what shifts are occurring. Sessile marine invertebrates are good candidates for this, as they cannot easily move if temperatures rise.

6. an assessment of whether current governance arrangements are well placed to deal with the challenges of conserving biodiversity in a changing climate

Conserving biodiversity involves more than just protecting whales, dugongs seabirds and koalas. We need to conserve all levels of the ecosystem if we are to have functioning systems. The following points are made in relation to all three: terrestrial, marine and freshwater environments:

- Current resourcing for biodiversity conservation is inadequate. Species loss is continuing (eg Christmas Island Pipistrelle) and increasing numbers species and ecosystems are being recognized and formally listed as threatened. Climate change impacts will only increase resources needed to manage and preserve biodiversity.
- More research is required to better understand impacts of climate change and amelioration methods. Current monitoring to assess impact on terrestrial ecosystems is inadequate.
- As species/ ecosystems move, boundaries of protected areas may need to be altered, and 'stepping stones' provided to enhance connectivity and movement.
- Some useful initiatives have been developed to promote and restore ecosystem connectivity at a landscape scale (eg Alps to Atherton, Gondwana Link, Kosciusko to Coast, Habitat 141: Ocean to Outback etc). These are huge undertakings and resources are limited. As a consequence, tangible progress on the ground has been slow to date but may certainly have worthwhile outcomes.

Marine environments:

Boundaries of existing marine protected areas may need to change as climate changes to preserve source and sink reefs, and to provide stepping stones to enhance connectivity and population migration.

More resources should be made available to those institutions that can actually document biodiversity (remembering much still remains to be described) - ie state museums. It is critical to record changes in the lower levels of the food chain such as invertebrates and not concentrate exclusively on the large charismatic species.

Freshwater environments:

Range shifts and reductions due to climate change are likely to lead to a decrease in the proportion of amphibians in protected areas, particularly for range-restricted species. Some species are predicted to suffer complete loss of core habitat (for example the newly described species of rainforest frog *Cophixalus* sp. nov., Thornton Peak, QLD; Williams 2006). In fact, many patches of habitat are isolated habitats and animals within these habitats have little potential for dispersal, especially rainforest endemics.

7. mechanisms to enhance community engagement

There are compelling arguments for greater involvement of local communities and engagement with members of the public interested in environmental issues and science in the biodiversity conservation arena. This engagement may take a variety of forms, including monitoring, change detection, 'citizen science' and remedial works. Incentives to protect and restore native vegetation and connectivity of ecosystems on private land and incentives for land (including traditional) owners to undertake introduced species and weed control should be provided.

Consideration should be given to the development and support of a suite of mechanisms (including incentives, volunteerism and citizen science involvement) to encourage greater on-ground and on-line community engagement in assisting with the management of climate change impacts on biodiversity.

8. <u>case studies of 'nationally important ecosystems'</u>.

Case study – Protection of unique reef habitat
The Museum contends that we should include Australia's coral reefs (not just the Great Barrier Reef), but also shallow coastal areas where Australia's population is greatest- ie the Eastern seaboard – where climate changes will be exacerbated by other anthropogenic impacts such as reduced water quality, loss of coastal habitats (seagrasses, salt marsh and mangroves), increasing use of estuaries, dewatering of rivers feeding estuaries and other coastal areas, aquaculture and increased fishing.

Case study – Protection of unique species of land snails
Land snails offer an instructive example. It is worth noting that Australia harbours a large number of land-snail species (with 800 species known from the eastern fringe of the Australian continent alone (Stanisic et al. 2010); and a proportion of unknown species likely to be much larger as we continue to discovery large numbers of new species in all regions of the continent (e.g. Koehler, 2010).

The acute moisture-sensitivity of land snails is reflected in their predilection for moist habitats and makes them ideal candidates for use as indicator species for faunal assemblages of such habitats. Most of species are micro-endemic with species ranges in more xeric regions being as small as a few kilometres in diameter (e.g., Willan et al., 2009, Koehler, 2010) – and perhaps some ten to max. 100 km in species from more humid regions (Stanisic et al., 2010).

Being restricted in their occurrences and quite specialised in their habitat requirements as well as being prone to desiccation, fires, and habitat changes, snails are particularly vulnerable to effects of climate change which may lead to shifts in these habitat conditions. Small ranges and fragmented occurrences, as typical for many snails, imply that even locally restricted changes will lead to extinctions – and that species have no means to follow geographical shifts in habitats, which may be caused by shifts in climate.

Case study - Phylogenetic resilience of corals
Evolutionary history and phylogenetic diversity (PD) are targets for biodiversity conservation because they represent many current and future benefits for humans ("ecosystem services"; Faith et al 2009). These benefits are reduced when branches of the phylogenetic tree are lost through extinctions. Resilience is greater when long branches have numerous secure descendants. Resilience is lost as extinctions continue within a taxonomic group. Successive species extinctions each may imply only a moderate loss of ecosystem services, until, abruptly, the last descendant species from a long branch goes extinct – and the long branch representing a large amount of PD is lost. Phylogenetic risk analysis guides conservation decisions that try to reduce risk of these worst case losses, or tipping point" outcomes.

Such tipping points were explored for the taxonomic group that is perhaps most threatened by climate and land use changes – the corals. Carpenter et al (2010) calculated that "32.8% of zooxanthellate coral [species] fall into threatened categories, compared to approximately 25% of mammals and 14% of birds...If Near Threatened species are added, the proportion of corals (57.8%) exceeds that of all terrestrial animal groups assessed to date...". These impacts may be even greater at the evolutionary history level. While threats are well-dispersed on the phylogenetic tree (lots of PD would still persist), there are many examples where entire monophyletic groups (existing families and genera) fall into IUCN threatened (or near-threatened) classes. Based on a large phylogenetic tree for corals, several cases representing potential tipping points and loss of resilience are clear. For example, all listed species within the genera *Catalaphyllia*, *Physogyra*, and *Euphyllia* are listed in one of the threatened or near-threatened categories. The coral phylogenetic tree shows that these are the only descendent taxa of a long branch, and so represent one example of potential loss of future benefits, and resilience, due to climate change impacts.

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