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Increasing impacts of climate change upon ecosystems with increasing global mean temperature rise

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Introduction: Climate change effects are already being observed on a wide range of ecosystems and species in all regions of the world (Rosenzweig et al., 2007), in response to the 0.74°C rise (ΔT_g) in global mean temperature (GMT) that has been experienced since pre-industrial times (Solomon et al., 2007). Such responses include extinctions, changes in phenology and shifts in species ranges (e.g. Root et al., 2003; Walther et al., 2002; Pounds et al., 2006). The literature contains a growing number of studies projecting increasingly severe impacts of further climate change on ecosystems and species around the world. However, these studies have largely been carried out independently from each other and have used a wide range of future climate scenarios making it difficult to compare results and obtain a clear picture of how impacts accrue with increasing global mean temperature rise. Such an aggregated picture is important because it both addresses climate change at the appropriate global scale, and it enables the evaluation of major policy recommendations such as the much discussed 2°C maximum limit proposed by the EU. This paper integrates the dispersed and fragmented literature on ecosystem impacts of projected climate change into a standardized set of projected impacts for different levels of annual global mean temperature rise, ΔT_g.
Methods**:** An extensive literature review was performed examining the impacts of climate change on ecosystems across the globe (Fischlin et al., 2007). References were then reviewed for specific information about climate change thresholds above which adverse consequences could be expected, taking note of the climate scenario and any general circulation model (GCM) used. The information on the climate change scenario simulated by each study was then converted to a common pre-industrial reference point for temperature. Upscaling was then carried out, as needed, for the different studies. The upscaling procedure involved the use of 0.5° x 0.5° resolution outputs produced from five GCM models, HadCM3, ECHAM4, CSIRO2, PCM, and CGCM2, by using pattern scaling and downscaling methods (Christensen et al., 2007). They were produced from up to four IPCC SRES emission scenarios (Nakicenovic et al., 2000) providing 13 different GCM patterns on which to base the upscaling.
Results**:** Projected impacts were found for all major world regions. Range losses and extinctions were projected for many taxa with vascular plants, birds, and mammals being particularly well represented. Many studies also project major losses of regional ecosystems as well as 'tipping points' in ecosystems, i.e. thresholds above which major components of ecosystems become irreversibly damaged, positive feedbacks emerge, or their functioning collapses. Most of these thresholds appear to lie around $\Delta T_g \geq 2.5$°C above pre-industrial. Significant negative impacts for range losses and extinctions and also damages to marine ecosystems, were projected to occur below a threshold of ΔT_g of ~2°C. However, it is also noticeable that projected impacts increase in magnitude, numbers and geographic spread once a 2°C threshold is reached. Beyond this, the level of impacts and the transformation of ecosystems become steadily more severe, with tipping points in ecosystems being rapidly crossed, and extinction risks accelerating and becoming widespread.
Conclusions: A literature-based assessment of the effects of climate change upon a wide range of ecological systems has shown that the negative impacts accrue as annual global mean temperature rise as little as 1.6°C (low end of the likely range of IPCC scenarios, Solomon, 2007) above pre-industrial, with some damages, range losses, and extinctions having already occurred. As temperatures approach and exceed 2°C above pre-industrial the geographic extent of negative impacts rapidly increases, including species range losses, extinctions and increasing damage to some critical ecosystem structure and functioning. As temperatures exceed 2°C above pre-industrial, the literature and models increasingly project impacts accruing to entire systems and spreading across a range of different species groups and regions. Several critical tipping points of ecosystem functioning are projected to be breached at a temperature increase of 2.5°C. These tipping

points represent either the collapse of entire ecosystems, or comprise impacts that are in our judgement dangerous, because they imply irreversible damages, such as extinctions of key species or the onset of positive feedbacks (CO_2 or methane emissions), accelerating climate change. The literature therefore suggests that impacts accruing as temperatures approach and exceed 2°C above pre-industrial represent 'dangerous anthropogenic interference' with ecosystems and would breach compliance with Article 2 of the United Nations Framework Convention on Climate Change.

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