

## Essay 2

# The impacts of climate change in the Tropics

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Richard Corlett obtained his first degree from the University of Cambridge in 1974, followed by a PhD in plant ecology at the Australian National University, with fieldwork in the highlands of Papua New Guinea. He has subsequently held teaching posts at the University of Chiang Mai, National University of Singapore, and University of Hong Kong. In 2012 he moved to the Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, in Yunnan, to take charge of a new Center for Integrative Conservation. His major research interests include terrestrial ecology and biodiversity conservation in tropical East Asia, plant-animal interactions, and the impacts of climate change. In addition to numerous scientific papers, he is the author of several books, including *Tropical Rain Forests: an Ecological and Biogeographical Comparison* (Wiley-Blackwell, 2011) co-authored with Richard Primack, and *The Ecology of Tropical East Asia* (Oxford University Press, 2009). He is a lead author for the 'Asia' chapter in the 2014 Report of the Intergovernmental Panel on Climate Change (IPCC) and a member of the steering committee of the IUCN Climate Change Specialist Group. He was elected President of the Association for Tropical Biology and Conservation (ATBC) in 2012.



## The impacts of climate change in the Tropics

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The climate is changing in the Tropics, as it is in the rest of the world (IPCC, 2013). The effects of steadily rising concentrations of greenhouse gases on the climate may be less obvious to tropical residents, however, because they are overlain by considerable natural variability. Much of this variability is driven by the El Niño-Southern Oscillation (ENSO) (see Figure E2.1). The Tropics has warmed by 0.7-0.8°C over the last century—only slightly less than the global average—but a strong El Niño made 1998 the warmest year in most areas, with no significant warming since. Climate models predict a further 1-2°C warming by 2050 and 1-4°C by 2100, but the rise will certainly not be as smooth as the graphs that are produced by averaging many different climate models.

Trends in rainfall over the last century are much less clear than those in temperature. Many tropical areas are now significantly wetter or drier than they were a century ago, and others show marked fluctuations. Predictions for future rainfall vary between models in most regions, reducing confidence in their usefulness. Climate

extremes are even harder to predict, but the low day-to-day variability of tropical temperatures means that a rise in mean temperatures of only a few degrees is almost certain to bring temperature extremes higher than any that occur today. There are good reasons to believe that other extremes—droughts, floods and high-intensity cyclones—will also increase in much of the Tropics, although none of these predictions are made with high confidence (IPCC, 2013).

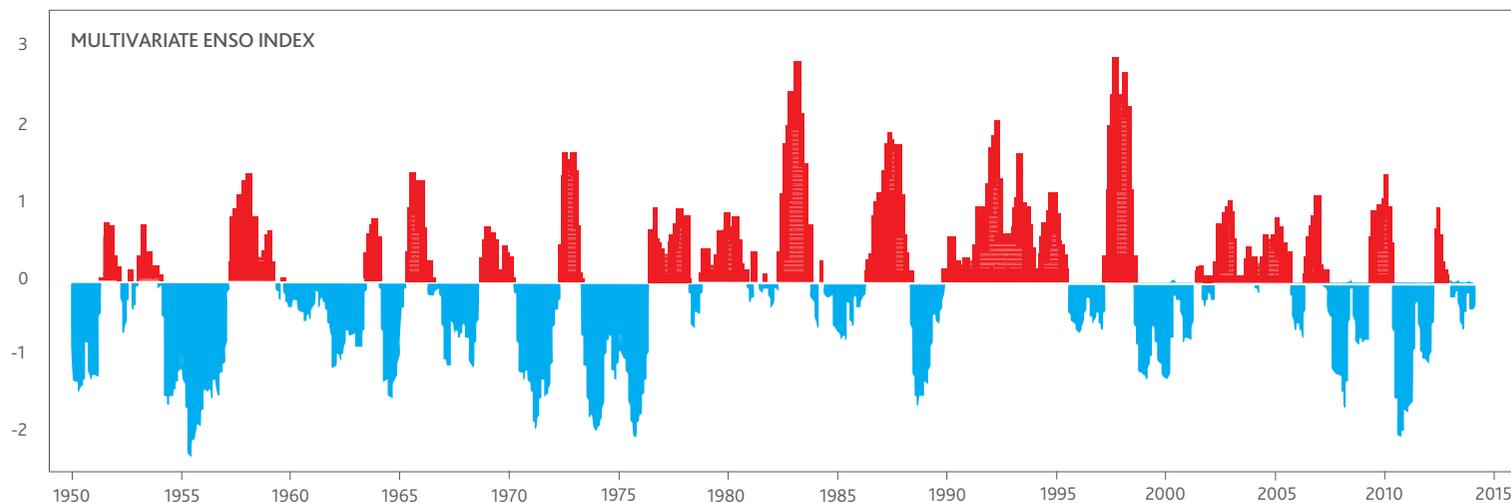
Tropical climates have changed in the past, with the most recent major change being the several-degree warming at the end of last glacial period, between 20,000 and 10,000 years ago. Temperatures have also been higher than now, although the last period that was consistently warmer than the present in the Tropics appears to have been the early Pliocene, more than 3 million years ago. But, although climate change is nothing new, there are very good reasons for thinking that the changes predicted for the remainder of the 21st century will be a major problem for the Tropics.

First, the models suggest that the rates of change will be faster than any known from the past, leaving little time for adaptation or movement to cooler areas. Second, although the Tropics have been warmer before, most of the last 3 million years has instead been cooler, suggesting modern species will be unlikely to have retained adaptations to these higher temperatures. Finally, and perhaps most important, rapid climate change is only one of the many stresses on plants, animals and people in the 21st century. Many of these other stresses will interact with climate change in ways that increase the negative impact of both. For example, the fragmentation of most natural habitats in the Tropics by agriculture and infrastructure will make it very difficult for species to respond to climate change by moving.

### The impacts of climate change: observed and predicted

High natural climatic variability, coupled with the rarity of long-term records in the Tropics, has

Figure E2.1 The El Niño-Southern Oscillation (ENSO) has a large impact on tropical climates.



Source: This graph shows the Multivariate ENSO Index (MEI) developed by the U.S. National Oceanic & Atmospheric Administration; positive values represent El Niño events and negative values La Niña events (<http://www.esrl.noaa.gov/psd/enso/mei/>).

so far made it difficult to detect the impacts of climate change on natural and human systems (IPCC, 2014). Moreover, the impacts of climate change are expected to interact with those of other, more direct, human impacts, including deforestation, population growth, increased urbanisation and pollution, making it difficult to pin down the major drivers of change in any particular case. Terrestrial impacts are clearest on high mountains, where both plants and animals have moved upslope in response to warming in several parts of the Tropics, while glaciers have shrunk on the highest peaks in the Andes, East Africa (see Figure E2.2), and New Guinea. In the sea, coral reefs across the Tropics have suffered unprecedented mass bleaching episodes as a result of rising sea-surface temperature extremes. Most other suggested impacts are less clear than these, however. It is tempting to treat recent floods, droughts and massive cyclones as manifestations of human-caused climate change, but the science is still not certain.

Predictions for the future add the uncertainties of the biological and social sciences to the already large uncertainties from the climate models. In the case of temperature, a significant increase is all but certain, but the impacts of changes in other climate variables are best stated as 'IF climate changes in a particular way, THEN the following impact is likely'. Although not strictly aspects of climate change, both sea-level rise and ocean acidification have the same ultimate causes (rising levels of atmospheric carbon dioxide), and both are certain to increase in a delayed response to atmospheric changes that have already happened.

It is simplest to consider the impacts on natural and human systems separately, but it is important to realise that these are rarely, if ever, independent. Many of the natural systems that will be impacted are important sources of ecosystem services to human communities, including fish from coral reefs and water from mountain ecosystems. Conversely, human responses to climate change impacts, such as diverting freshwater water supplies, building sea walls, or expanding agricultural land, are

expected to have large, additional impacts on natural systems.

## Impacts on natural systems

Outside the Tropics, it is possible to get a rough idea of future changes in natural systems by looking towards the equator, where temperatures are already warmer. London, for example, is expected to have a climate more like the present-day south of France by 2100. Even in the temperate zone, a simple poleward migration of species and ecosystems is an oversimplification, but it is a useful guide. In the tropical highlands one can look downslope to see what is coming, but in the tropical lowlands there is usually no existing analogue for the climates predicted for the second half of this century. Equatorial Singapore will not just be warmer than it is now, but warmer than anywhere on Earth with year-round rainfall.

These 'no-analogue futures' leave predictions dependent on models, but we currently lack the

data needed to test whether their simulations are realistic. Scientists have warmed up insects, frogs and tree seedlings in their laboratories, and tree branches in the field, but until someone warms an entire tropical forest for several years we are unlikely to be able to say with confidence what will happen. Predictions for biodiversity in the lowland Tropics currently range from little change to a drastic 'lowland biotic attrition', as species retreat upslope or die, and are not replaced.

There are also concerns that warming, with or without changes in rainfall, could convert tropical forests, which are currently a huge net 'sink' for carbon dioxide (i.e. they absorb more than they emit), into a net source. There is currently evidence on both sides of this debate and model predictions depend strongly on what assumptions are built into them. In particular, there have been suggestions that the eastern Amazon, which is expected to get both warmer and drier over future decades, could be subject to massive forest die-back and a transition to a new, fire-adapted state, with fewer species

**Figure E2.2** Shrinking glaciers on Mount Kilimanjaro in 2009. More than 80% of the ice cover on this mountain has been lost since 1912.



Image: Muhammad Mahdi Karim (GNU Free Documentation License, Version 1.2, Wikipedia).

and less stored carbon. Most models suggest that the risk of such a transition is relatively low when only climate change is considered, but rises rapidly when the drying effects of other human impacts—particularly logging and forest fragmentation—are also factored in.

An additional factor that must be considered is the direct impact of higher levels of carbon dioxide—the major greenhouse gas—on plant growth. There are physiological reasons for believing that rising carbon dioxide levels may partly offset the adverse impacts of climate change on plants by the so-called 'carbon dioxide fertilisation effect'. Indeed, there is increasing evidence from across the Tropics that this is already happening, although not all the data supports this conclusion. Moreover, higher carbon dioxide levels are expected to favour trees over tropical grasses, and may already be contributing to observed increases in tree invasions into savannas. There is also some evidence—again debatable—for an increase in the abundance of lianas in tropical forests, which may again be driven by rising carbon dioxide levels.

In comparison with the tropical lowlands, tropical montane ecosystems have potential advantages in withstanding climate change impacts, including generally lower direct human impacts and much steeper temperature gradients, so that plants and animals will not need to move as far in order to compensate for rising temperatures. However, most mountains are basically conical in shape, meaning that the area available declines rapidly with altitude, reaching zero at the summit. If species are pushed uphill by rising temperatures they will be crowded into a smaller and smaller area, with 'mountain-top extinction' inevitable if warming continues long enough. Tropical mountains support numerous species with small geographical ranges—often confined to a single mountain—and these species may be among the most vulnerable to climate change.

The plants and animals of freshwater ecosystems—streams, rivers, lakes and wetlands—are similarly isolated from each other by inhospitable habitats and potentially vulnerable to climate change. However, any

impacts so far have been difficult to disentangle from natural variability and the effects of increasing human use of freshwater resources. Future impacts from rising water temperatures and changes in water flow will continue to interact with dam construction, pollution, and land-use changes.

Coastal systems will also face threats from rising sea-surface temperatures, as well as increases in sea-level and ocean acidity, although these impacts can again be hard to distinguish from the many other effects of increasing development on tropical coastlines. Any increase in cyclone frequency and intensity would also be felt most strongly near the coast. The climate change impacts observed in recent decades largely reflect the warming sea, with many tropical species expanding their ranges towards the poles. Rising sea-levels (about 20 cm since 1900) may also be having an impact on coastal systems already, by adding to storm-surge maxima and thus increasing flooding and coastal erosion. This impact is certain to increase in the coming decades. Undisturbed coastal ecosystems can usually retreat inland in response to rising sea-levels, but on human-occupied coasts retreat is often prevented by fixed barriers intended to protect agriculture and infrastructure. The resulting 'coastal squeeze' will eliminate some coastal communities and restrict others.

The most dramatic impact of climate change observed so far across the Tropics has been the increasing frequency and scale of mass bleaching of coral reefs and, in some cases, the subsequent death of the corals (see Figure E2.3). These events correlate well with high-temperature extremes, leaving little doubt that this is a real impact of recent global warming. Ocean acidification appears to have a synergistic impact with temperature extremes on corals and other reef-building organisms, leading to plausible predictions that coral reefs as we know them will have largely disappeared by 2050. In contrast, ocean acidification is expected to enhance the growth of sea-grasses, algae and other plants through the carbon dioxide fertilisation effect.

Figure E2.3 Coral bleaching in the Keppel Islands, Great Barrier Reef Marine Park, Australia in 2006.



Image: Ove Hoegh-Guldberg, Global Change Institute, University of Queensland.

The impacts of warming also extend out into the tropical oceans, with shifts in the distributions of species already observed and expected to intensify in the coming decades. By mid-century there are predictions that the species richness and productivity of tropical oceans will have declined markedly as species shift polewards and are not replaced.

Natural systems have an innate capacity to adjust to climate change, by changes in the distribution and abundance of species and ecosystems, as well as by the acclimation (i.e. adjustments within the lifetime of an individual organism) and evolution (i.e. genetic changes over multiple generations) of individual species. There must be limits to this capacity, but we are currently unsure when they will be reached: another 1°C? 2°C? more? In practice, thresholds for irreversible change will certainly vary between species and may already have been exceeded in some of the more sensitive organisms.

## Impacts on human societies

Compared with the impacts on natural systems, both the detection of impacts on human societies and the attribution of these impacts to climate change are considerably more difficult. Not only do human problems rarely have a single cause, but they often also come at the end of long—and sometimes tortuous—causal chains. The impacts from extreme climatic and climate-associated events—cyclones, floods, droughts, storm surges etc.—may be obvious, but such events are difficult to attribute confidently to climate change. Conversely, the gradual changes in climatic variables which we can confidently attribute to climate change have impacts that are difficult to detect against a background of rapid social and economic change arising from numerous other factors.

The most straightforward climate-change impact on human society is the effect of high temperature extremes on human health. Heat waves already kill more people than any other climatic event and their frequency and severity

is almost certain to increase in the coming decades. The old and sick are most at risk of dying. Many more people are hospitalised for heat stroke and outdoor work may become impossible during the warmest months of the year. Other potential impacts on human health are less straightforward, but an increased risk of food- and water-borne diseases is likely and lowland disease vectors, such as mosquitoes, are expected to spread into tropical highlands that are currently too cool to support them. Health will also be affected indirectly by impacts on freshwater resources and the food supply.

Climate change is expected to further reduce the freshwater supply for people, agriculture and industry in presently dry areas of the Tropics and subtropics, although the generally low confidence in current rainfall predictions creates a lot of uncertainty. The continuing loss of glaciers from tropical mountains may cause a temporary increase in water flows in the streams they feed, but will also eventually reduce the availability of water downstream. Several major rivers flow towards the Tropics from the extra-tropical Himalayas and Tibetan Plateau, but glaciers and snowmelt make a significant contribution to their flow only in their upper reaches. Rising sea-levels increase the risk of saltwater intrusion into freshwater sources near the coast. The frequency and intensity of droughts is also expected to increase in some parts of the Tropics, as is the flood risk from extreme rainfall events. Floods near the coast will be exacerbated by rising sea-levels, with fixed infrastructure at particular risk. Small islands, which are effectively all coast, will be particularly vulnerable.

The potential impacts of climate change on the food supply are complex. Impacts on agricultural production will be variable, with both winners and losers depending on local circumstances. Impacts in the tropical lowlands are expected to be mostly negative as the temperature tolerance of major crops is exceeded, although, as with natural vegetation, the potential benefits of carbon dioxide fertilization are a big uncertainty. The opportunities for adapting agricultural

practices to changing climates will also be important in determining future crop yields. In contrast, agriculture in tropical highlands may benefit from rising temperatures.

Several studies have predicted large declines in the fish catch in tropical oceans, as marine productivity falls, coral reefs disappear, and valuable species move polewards. Reductions in the average body size of tropical marine fishes have also been predicted. Freshwater fisheries may be threatened by warming and changed water flows, although the many other threats to freshwater ecosystems, including overfishing, water abstraction, pollution and dam construction, make the impacts of climate change hard to separate.

Urban societies face all the potential problems already discussed, plus additional threats from sea-level rise and cyclones when they are situated in low-lying coastal areas. Vulnerability is often associated with poverty, although nobody is immune to major failures in infrastructure. Many tropical cities are surrounded by vast informal settlements, often on steep land that is highly vulnerable to extreme rainfall events and their consequences. On the other hand, well-managed cities provide services, such as early warning systems, disaster relief and health care, that are often not available in rural areas, partly buffering residents from the impacts of climate extremes.

Like natural systems, human societies have an innate capacity to adjust to climate change, and the options for adjustment in the future are considered in more detail below. Some sectors of society are more vulnerable than others, either because they are more exposed to climate change or because they have a lower capacity to adjust. In general, it is the poorest people who occupy flood-prone sites and steep hillsides, and they also have least access to supporting infrastructure and government services. Indigenous people may be unusually vulnerable because of a heavy dependence on natural resources and strong cultural ties to the land, although the degree of social marginalisation is another key variable.

There is historical evidence that climate change—or, at least, a succession of 'bad' years—has triggered the collapse of civilisations in the past, and there have been suggestions that the coming decades will see increased civil unrest and violent conflict as a result of rapid climate change. Flash-points could include competition for water or food, or the impact of extreme climate events. However, the globalisation of disaster relief has made the world less vulnerable to localised disasters, and these predictions may be excessively pessimistic.

## Mitigation and adaptation

Both climate and sea-level have a delayed response to rising greenhouse gases, so the Earth is already committed to some additional warming and sea-level rise, even if greenhouse gas concentrations could be stabilised at present levels. At least in theory, any additional change is under our control, and could be avoided, although the long working life of expensive energy infrastructure, such as coal-fired power stations, makes a rapid reduction in emissions extremely unlikely. Reducing the amount of future climate change by reducing greenhouse gas emissions (or increasing sinks, such as forests) is known as climate-change mitigation, and is distinguished from climate-change adaptation, which is reducing the vulnerability of human and natural systems to change.

Mitigation has been considered a task for international bodies, with the support of national governments, but the failure to reach a binding international agreement limiting future emissions suggests that this approach is not working well. Local governments and businesses have sometimes had more success in promoting low-carbon alternatives, but the real need is for a cultural change away from our current, unsustainable, dependence on fossil fuels. Cultures change from the bottom up, suggesting a key role for individuals and communities in achieving the necessary global goals. Unfortunately, the politicisation of climate change issues in many countries has made this more difficult, since attitudes to action on climate change have

become packaged with unrelated issues, leading to an exaggerated polarisation of views.

Adaptation is not an alternative to mitigation, since rapid climate change will continue until we stabilise greenhouse gas concentrations and must eventually exceed even the most optimistic assessment of our capacity to adapt. However, adaptation is essential and in many cases can result in a significant reduction in adverse impacts. Uncertainties in the predictions for future climates favour 'low regrets' strategies which provide benefits under current climate conditions as well as a range of future climates. Some of these measures produce co-benefits for other development goals, making them particularly attractive.

For example, increasing trees and other greenery in urban areas would help reduce the 'urban heat island effect', which increases the threat from heat waves, but will also have co-benefits, such as improved public health. Similarly, forest restoration can contribute to mitigation by storing carbon and to adaptation by directly cooling the local climate, while also benefitting biodiversity conservation. Other potential low-regrets measures include better early-warning systems, climate-proofing of infrastructure, climate-sensitive land-use planning, and improvements to environmental education.

There are other adaptation options where the benefits depend on specific future climate scenarios. While these measures may be less easy to get implemented than those with current benefits, their potential impacts can be greater. Examples include breeding new crop varieties for tolerance of future climatic conditions, extending protected areas to include land that will be critical for conservation in the future, and the 'assisted migration' of threatened plant and animal species to locations where suitable future climates are expected. Conservationists are currently working to identify the species that will be most vulnerable to climate change so that conservation effort can be focussed where needed.

Biofuel crops were initially seen as a low-regrets mitigation option. In theory, biofuels can reduce net carbon emissions, because the carbon dioxide

released by burning them is withdrawn from the atmosphere during growth, while at the same time providing economic benefits to the tropical countries that grow them. In practice, a net carbon gain has been hard to achieve with biofuel crops, because carbon-rich vegetation is often cleared for their cultivation. Moreover the economic benefits have been partly offset by negative impacts on food production and conflicts over land use. Improved land-use planning and new technologies that can utilise a wider range of plant materials may make biofuels a viable mitigation option for the Tropics, with social and environmental co-benefits, but a cautious approach is needed.

## Conclusions

The global risks to natural and human systems from climate change are becoming increasingly obvious (IPCC, 2014), but most of the evidence come from outside the Tropics. In consequence, the word 'uncertainty' appears many times in this essay. Climate change impacts depend on interactions between complex physical, biological and social systems, none of which are well understood at present. The global climate models are gradually improving and now incorporate feedbacks from ecosystems, but their predictions depend heavily on the trajectory of greenhouse gas emissions over the coming decades, which in turn will be influenced by socioeconomic factors and technological change. This suggests that although the overall uncertainties in impact prediction can be reduced, they cannot be eliminated. Uncertainties are inherent in any complex system, but climate scientists have so far done a poor job of communicating this to decision-makers and the general public. This is unfortunate because the most important message from the recent IPCC reports is that our fate is in our own hands.

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Flooding from Cyclone Nargis, Burma/Myanmar.  
Image: Neryl Lewis RRT.