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Conservation, climate change, and tropical forests

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15.1 INTRODUCTION

Conservation of tropical forests in the face of climate change is an immense task, because of the huge losses already suffered to habitat loss and because of our still rudimentary knowledge of the biology of these systems. For example, in Southeast Asia, most moist tropical forest has already been lost, resulting in the severe imperilment of hundreds of well-known species, as well as the probable extinction of thousands of species before they are described by science (Brooks *et al.*, 1997). In this setting, climate change will alter the abundance and distribution of many species whose continued existence is already precarious, in a landscape that permits little if any scope for range dynamics.

While conservationists struggle against habitat loss, we seemingly lack even a strategy for coping with climate change. But that strategy is not completely elusive. It is clear that a two-pronged response is needed to effectively cope with climate change (Hannah *et al.*, 2002a). First, on-the-ground conservation strategies must begin to consider climate change. Expanding planning horizons, modeling and assessing possible climate change effects, and monitoring potentially sensitive species are all elements of climate change integrated conservation strategies that are within easy reach. The second, and more difficult, element of conservation response is that of constraining greenhouse gas levels in the atmosphere (Hannah *et al.*, 2002a). It is clear that no conservation strategy can be successful on the ground in the face of ever mounting climate change. Greenhouse gas levels must be stabilized in the atmosphere to limit climate change, implying a huge transition in the energy economy away from fossil fuels (Lackner, 2003).

In this chapter we will describe the challenges climate change poses to tropical forest conservation, followed by an analysis of the appropriate responses and their potential scope. We will then explore greenhouse gas stabilization in the atmosphere. Taking into account the possible scope of coping with climate change in conservation strategies, what level of atmospheric greenhouse gases is "safe" and what would be required to reach those targets?

15.2 CONSERVATION CHALLENGES

Several distinctive characteristics of tropical forest response to climate change pose significant challenges for conservation. Among these are the climate-making role of tropical forests, uncertainties about past responses, the introduction of warmth on an already warm inter-glacial climate, the critical role of precipitation in tropical forest eco-physiology and the synergies of climate change with ongoing habitat loss. This section will describe each of these challenges briefly.

Tropical moist forests have interactions with regional and global climate that have profound implications for their conservation. The Amazon Basin in particular plays meso- and global-scale climatic roles (Cox *et al.*, 2000, 2004; Betts *et al.*, 2004; Marengo, 2004). The basis of this effect is the influence tropical forests have on moisture-cycling and the regional water balance. At a plot level, removing forest changes the radiative properties of the surface and reduces moisture release by evapotranspiration (Pitman *et al.*, 2000; Chapter 2 in this book). These effects result in increased convection over the cleared parcel and may result in increased precipitation if the clearing is small and isolated. As the amount of clearing increases, the effect changes to one of reduced precipitation as convection has increasingly less surrounding moisture from evapotranspiration on which to draw.

At the scale of large forested areas—such as the Amazon Basin—the net effect of forest moisture turnover is to cycle moisture entering the system from the tropical Atlantic, making the western parts of the basin significantly moister than would be the case in the absence of forest (Chapter 2 of this book; Bush, 1996). Clearing of a substantial fraction of the basin may therefore lead to additional forest loss due to loss of moisture-cycling and regional drying. This positive feedback appears to have repercussions at a global scale as well (Cox *et al.*, 2002). When carbon and surface vegetation models are incorporated into GCMs, climate change drying in eastern Amazonia leads to forest loss, progressive drying in western Amazonia, and accelerated global warming due to massive releases of CO_2 from the Amazon. Avoiding these effects may require maintaining a substantial fraction of the tropical forest cover of the basin as a whole.

A second feature complicating the conservation of tropical forests in the face of climate change is the limited knowledge of these systems' responses to past change (Flenley, 1998). This can be a key limitation is assessing the possible natural precedents for response to rapid climate change. Paleoecological evidence from the flank of the Andes suggests that forests responded to glacial–interglacial cycles, but not to the rapid climate "flickers" that appear to characterize North Atlantic climate and vegetation responses (Bush *et al.*, 2004). The very rapid millennial or shorter timespan climate "flickers" observed in Greenland ice cores are not reflected in the pollen record obtained from lakes on the flanks of the Andes. This could indicate either that these climate flickers did not occur in the tropics or that vegetation did not respond to them.

Other aspects of past response are still debated. While it is clear that tropical forests around the world have responded to climate change in the past (Flenley, 1998), the exact pattern is not well worked out for areas as significant as the Amazon (Bush, 1994). The retreat of Amazonian forests into "Pleistocene refugia" has been discounted based on a number of lines of evidence (Willis and Whittaker, 2000). However, deeper time refugia have been proposed (Haffer, 1997). It has also been suggested, based on modeling, that Amazonian forest cover may have been maintained in glacial–interglacial cycles, but that forest structure (as indicated by leaf area index in the models) may have shifted significantly, driving speciation in the absence of "refugia" (Cowling *et al.*, 2001). This suggests that direct CO_2 effects might impact evolutionary processes in ways that would be very difficult to control or modify through conservation actions.

The relative lack of evidence about past biotic change is aggravated by the lack of climatic precedents for the speed and nature of expected future change (Overpeck *et al.*, 2003). Warming is projected to be rapid and will occur in the context of a warm interglacial climate (IPCC, 2001). Most rapid warming over the past 2 million years has occurred in transitions out of glacial conditions. While some interglacials were warmer than the current climate, they then cycled into cooling towards a glacial period. Physical and biotic analogs to the expected warming on a warm climate are largely absent.

While lack of information is an obstacle, we have abundant data that demonstrate that all ecosystems, including tropical forests, experience climate change on a species-by-species basis. This individualistic response to climate change is reflected in numerous temperate records and in the limited tropical record. A Gleasonian view of communities as ephemeral collections of species with like climatic and biophysical tolerances is supported by this evidence. The challenge posed to conservation is how to deal with transitory communities. If climate change is to tear contemporary communities apart, as component species respond individualistically, there is no absolute baseline reference. Pre-European contact or pre-disturbance ecosystem conditions are peculiar to one point in history. Trying to replicate these conditions under future climates that have no exact past analog has no precise scientific foundation.

As no-analog communities emerge under climate change, another conservation problem surfaces. We have no precedent for managing these communities. So, just as their composition poses problems for the definition of conservation goals and end-points, the processes of these communities pose problems for the definition of appropriate management practices. Without objective goals or management points of reference, conservation becomes relative at best and subjective at worst. Responding to the challenge faced by loss of reference points is common to all ecosystems facing climate change, but may be particularly acute in the poorly understood and mega-complex tropical forests.

Finally, the imposition of dynamics on an already severely depleted and fragmented natural system is one of the great challenges faced by tropical forest conservationists confronting climate change (Peters and Darling, 1985; Hannah *et al.* 2002a). Plant communities have responded in step with remarkably rapid climate changes in the past (Markgraf and Kenny, 1995). But these responses have taken place in fully natural landscapes, in which mechanisms such as micropockets of vegetation change could persist and serve as expansion fronts for subsequent change (McGlone, 1995; McGlone and Clark, 2005). Current patterns of human land disturbance indicate that most areas of the planet are now fragmented (Hannah *et al.*, 1994; Sanderson *et al.*, 2002), obscuring or obliterating many of the mechanisms for rapid response to climate change.

Tropical forests are certainly not immune to heavy fragmentation. Most of the global biodiversity hotspots fall in tropical forests, and the hotspots by definition have lost 70% or more of their primary habitat (in addition to the more widely appreciated criterion of high endemism) (Myers *et al.*, 2000). And even large forested areas such as the Amazon have undergone highly publicized fragmentation.

Yet, the amplitude of dynamics relative to fragmentation in the tropics remains poorly understood. In one of the best studies of tropical dynamics, Bush *et al.* (2004) have demonstrated that vegetation responses on the Andean flank are quite different from the records described for more temperate forests. In these Andean forests, directional change, though present, is indistinguishable from background change at any particular point in time. Does this mean that climate "flickers" were less pronounced or absent in the tropics, that vegetation response to flickers was muted, or that the records obtained to date cannot resolve the response (e.g., taxonomically)? There will be no hard answer to these questions until new data are literally dredged up from the lakes of the tropics. For now, ecologists can only be concerned that fragmentation may be a serious constraint relative to amplitudes of even background change in these complex systems.

Addressing all of the challenges discussed here will be complicated by the massive uncertainty in climate models about the magnitude and even sign of possible precipitation changes (IPCC, 2001). While there is much greater agreement about warming, consensus on precipitation change, which is critical in determining water balance, remains elusive. Water balance may be a more critical limiting factor than temperature for both tropical moist and tropical dry forests (Pacheco, 2001). Until the uncertainties associated with precipitation projections are reduced, it may be very difficult to assess possible impacts on tropical forest and appropriate conservation responses.

15.3 CONSERVATION RESPONSES

The regional feedback between tropical forests and climate is one of the conservation challenges most specific to tropical forests. The effect is expected to be greater for tropical moist forest than for tropical dry forest (Pitman *et al.*, 2000) and greater for the tropics in general than for temperate areas (Woodwell *et al.*, 1998), although the effect can play very important roles in higher latitudes as well (Pielke, 2001).

The spatial dependence of the forest–rainfall effect has been tested in the Atlantic Forest of Brazil (Webb *et al.*, 2005). In that study the relationship between forest cover and rainfall was found to be greatest at large spatial scales. The authors compared the scale of the forest–rainfall effect with areas needed to conserve mammals with large-range sizes, concluding that both area-demanding species and the forest–rainfall relationship required large reserves.

Perhaps the ultimate forest–rainfall system is the Amazon Basin. Here rainfall in the east is recycled many times through the forests of the basin, and, in fact, much of western Amazonia might not be moist forest without the rainfall generated (Betts *et al.*, 2004). Bush (1996) has suggested that preserving this moisture-recycling is probably more critical in setting conservation goals for the Amazon than are species-based concerns. Bush's suggestion is supported by the results of Webb *et al.* (2005) in the Atlantic Forest, a system with much less pronounced moisture-recycling than the Amazon. If the Amazon has a stronger forest–rainfall effect, it seems likely that the correlation between rainfall effect and scale will be even stronger, requiring even larger reserves.

The type of reserve needed to maintain forest cover may be very different from that needed for conservation of biodiversity, however. It is forest cover and physical properties that are important in the forest–rainfall effect, rather than functioning native ecosystems, so multiple-purpose reserves or even some types of plantation tree cover may be effective in maintaining moisture-recycling. At the same time, native ecosystems provide many other benefits to human society and biodiversity conservation, so the moisture-recycling properties of forest cover provide an additional strong reason for large protected areas in the Amazon. Indigenous reserves, multiple-use forest reserves and nature reserves may all depend one on the other for sufficient forest cover to maintain moisture-recycling in the basin and the future of the region's forests.

Our limited knowledge of the paleoecology of the tropics suggests that research is a critical component of conservation of tropical forest systems. Paleoecological pictures of Asian, African, and South American forests have emerged over the past 30 years (Maley, 1996; Flenley, 1998; Colinvaux and De, 2001). Yet many chapters remain to be written. Quantum improvements in spatial, taxonomic, and temporal resolution are all possible for most regions of the tropics. Some of the most celebrated of tropical forests, such as the Amazon, are among those about which the least is understood concerning past responses to climate change. The lesson for conservation is to recognize, and be open to, major research advances that will require rethinking and readjustment of conservation strategies.

The unprecedented speed and magnitude of coming change is an issue that is not unique to the tropics. Indeed, dramatic changes in the high latitudes in the early part of this century may overshadow or obscure huge tropical changes. The complexity of tropical forests and lower magnitude of change (at least in warming) will serve to make the tropical changes less obvious and slower to be documented, yet the sum impact on biodiversity as measured by species extinction may in the long run be much greater.

The recently documented amphibian extinctions in tropical forests of South America belie the idea that tropical extinctions will be slower or less dramatic. In these extinctions, synergy between climate change and chytrid fungal disease has resulted in a dramatic spate of extinctions that would not be predicted based on models of range shifts with warming. If such synergistic, threshold-linked extinctions turn out to be common, the tropical impacts of rapid large climate change may outshadow high-latitude change. It is difficult to suggest conservation responses to such unexpected effects. However, now that one such wave of extinctions has been documented, it is clear that two priorities are monitoring for rapid population crashes and capacity for rapid institution of captive breeding programs where such crashes are observed.

Individualistic species response and no-analog communities present parallel challenges to conservation. Each implies lack of historic or paleoecological precedents for acquisition and management, respectively. Resilience has been suggested as a principle to guide both acquisition and management, and for coral reef communities there is emerging evidence that properties associated with resilience can be defined (Salm *et al.*, 2001). However, in the more physically and biologically complex tropical forest systems, properties that may convey resilience may prove more elusive. It is far from clear that resilient forests would be the most diverse, suggesting a possible loss of biodiversity to attain resilience. Nonetheless, one principle that is clear is that removing current stressors is good for forests now and maintains biodiversity, at the same time that it makes forests more resilient to climate change (Hansen *et al.*, 2005). The resources for even this first step are far from secured, as will be discussed below.

Responding to dynamics in fragmented landscapes depends heavily on regional context and the relative scale of the two phenomena. The scale of the minimum dynamic unit in the Amazon may be nearly the entire basin owing to moisture-recycling, while in Central African forests—where moisture-recycling is less pronounced—the minimum dynamic unit may be much smaller and defined by the area demands of large species, rather than by the forest–rainfall effect. The only answer from a conservation viewpoint is to be aware of these effects and craft conservation strategies which incorporate careful consideration of scale and process. There is no substitute for intelligent design.

Uncertainty will continue to be high in impact assessments of climate change on biodiversity, yet we have done so little in our conservation strategies to get ready for climate change that there are many steps that can be taken with certainty. The following section describes some of the conservation strategies that can be employed to take these early steps.

15.4 CONSERVATION STRATEGIES

Conservation responses to climate change are drawn from the existing mainstays of conservation strategies—protected areas, conservation in multiple-use lands, connectivity between conservation areas—with new emphases and drawing on new elements necessary to respond to the challenges of a dynamic climate. In this section we will discuss these new and existing tools, and outline their application to the conservation challenges identified above.

Perhaps the greatest impediment to sound conservation in the face of climate change is the fact that present conservation systems are incomplete. The current global network of protected areas does not represent all species and is vastly underfunded, particularly in the tropics (James and Green, 1999; Rodrigues *et al.*, 2004). Responding to climate change would be a great challenge even in the presence of a comprehensive and well-funded system of parks and conservation measures. The problem of dealing with climate change is magnified when species range dynamics, alterations in phenology, and other changes must be addressed at the same time as completing species representation and meeting basic conservation management needs. Worse, the actions needed to confront the climate change challenge must compete for resources with these other, fundamental and often more urgent needs.

Therefore, completing representation of protected areas and adequate funding for basic management of parks and other conservation measures is the number one priority for addressing climate change. The representation and funding deficiencies are greatest in tropical forests. Over 1,400 species are under-represented in current protected areas considering vertebrates alone, virtually all of which are in the tropics (Rodrigues *et al.*, 2004). The global shortfall in protected area funding alone is estimated at $1.5 billion annually, with the majority of the shortfall occurring in the tropics (James and Green, 1999).

Connectivity between conservation areas is much less well-developed than the protected areas network, and is often presumed to be crucial in responses to climate change (Hannah *et al.*, 2002b). In principle, connectivity is an advantage as climate change dynamics become more pronounced. Not all connectivity is equally good for climate change response, however. Connecting forests along spines of mountain chains or ridgetops may not be as effective as connecting lowlands and uplands. Species will move upslope with warming, so connecting ridgetop forests has relatively less benefit than connecting lowlands and uplands. Similarly, a unit of connectivity in lowlands may be less relevant in climate change strategies than a unit of connectivity in uplands. This is because lowland species experience range shifts over relatively great distances as climate changes, while montane species are more numerous and experience range adjustments on smaller scales. Montane connectivity may therefore be more effective in species conservation on a per-unit basis. Thus, not all connectivity is equal from the perspective of climate change, and large investments in connectivity in the name of climate change should be qualitatively and quantitatively weighed against other conservation options.

For example, perhaps the most cost-effective action in a climate change conservation strategy is to invest in protected areas that harbor both species present range and their projected future ranges. Such investments offer the opportunity to improve both species current representation in protected areas and their potential future representation. In contrast to strategies to connect disjunct present and future ranges through connectivity, this approach is relatively robust to model uncertainty and it is a “no regrets” action (Williams *et al.*, 2005).

Beyond protected areas and connectivity, several new or modified conservation mechanisms will be important in dealing with climate change. These include most prominently vertical and lateral coordination of conservation planning and action. Vertical coordination is needed to ensure that national, regional, and local strategies work in concert in response to climate dynamics. Lateral coordination is needed between agencies to ensure that sectoral strategies are similarly aligned. This coordination currently exists, but will require conscious and systematic development as climate change intensifies. For example, strategies to promote transitions to new vegetation types must be coordinated across regions and between management agencies to ensure consistent management strategies and outcomes.

Creatively applied, these tools can make a substantial contribution to meeting the challenges posed by climate change (Hannah *et al.*, 2002b). Protected area systems can be expanded to compensate for range shifts resulting from climate change. Corridors can be designed specifically for climate change where range translocations for multiple species are anticipated. Conservation planning can adopt longer timeframes and emphasize vertical and lateral coordination to help improve the resilience of management strategies to climate change. Each of these tools can be fit to the climate change biology of individual regions.

For instance, for Amazonian tropical forests, protected area strategies must be sized and located with both species conservation and climate maintenance in mind (Bush, 1996a). The forest area required for maintaining the internal moisture-recycling of the basin may be larger than that required for representing all species. The location of the conserved forest is important for both biodiversity conservation and climate maintenance, but the optimal geographic configurations of the two may not exactly overlap. Simultaneous consideration of both biodiversity representation and climate maintenance may be important for other moist tropical forests as well. This is a politically sensitive issue. For instance, the Brazilian government has been implementing conservations units in some parts of Amazonia, that have generated reactions among soybean producers and the timber industry.

Management in the face of the uncertainties surrounding tropical forest response to climate change will require patience and adaptability. If tropical forests have not faced rapid climate flickers in the past, they may be poorly adapted to cope with rapid future change (Bush *et al.*, 2004). Yet, their physiology may be relatively robust to warming, in comparison with temperate and boreal species. By the time climate change provides a practical demonstration of which of these factors may prevail, it will be far too late to address the source cause of that change. It is therefore prudent to consider how, and at what levels, atmospheric greenhouse gases (GHGs) could be constrained.

15.5 GREENHOUSE GAS STABILIZATION

The global instrument for dealing with climate change—United Nations Framework Convention on Climate Change (UNFCCC)—is designed to avoid dangerous interference in agriculture, economies, and ecosystems (Schneider, 2001). Since coming into existence at the time of the 1992 Earth Summit, it is becoming increasingly apparent that ecosystems are the most sensitive of the three (O'Neill and Oppenheimer, 2002).

There is statistically sound evidence of responses in nature to the climate change that has already taken place: changes in flowering and nesting times, changes in distribution of birds, butterflies, and some marine organisms (Parmesan and Yohe, 2003; Root *et al.*, 2003). More disturbing is the first extinction associated with climate change (in conservation-conscious Costa Rica) and the widespread and massive bleaching of coral reefs from warmer seas added to other stresses (Walther *et al.*, 2002). Ecosystem failures—like those of corals and the 3.5 million acres of Alaskan spruce weakened by over 15 years of above-average temperature and dying from insect attack—can be considered a preview of more such events to come.

As scientists look ahead at the impacts of additional climate change on biodiversity, a consistent pattern is emerging, no matter how imperfect, of serious biological degradation and species loss. Compounding the problem of climate change *per se* are the ubiquitous human-modified landscapes that create an obstacle course to the movement of organisms and survival of species: the normal response in past climatic changes—such as the glacial–interglacial swings dominant in the recent geological past of the northern hemisphere.

The convention specifically addresses rapidity of climate change, citing the need not to exceed rates at which species can adapt naturally. Ignoring the distinct possibility that it is a mistake to assume climate change will only be gradual and never have abrupt episodes, it is nonetheless clear that some species and ecosystems will not be able to adapt above certain levels of climate change no matter how leisurely the rate of change. Ecosystems of low-lying islands will succumb to sea level rise and those on mountain tops will simply have nowhere to go at higher altitudes as it becomes too warm for them to survive where they are. Safe levels of climate change would avoid such ecosystem disruption and the associated wave of extinctions.

So what might constitute safe levels? Where we are right now is probably safe even with 0.8°C of average global warming plus whatever additional warming would take place because of the lag between increase in gases and temperature rise. But, it is impossible to stop at this level because of rates of emissions from current energy use (IPCC, 2001).

There seems to be a growing consensus that a safe level would be at carbon dioxide concentration of 450 parts per million or less (the pre-industrial level was 280 p.p.m.; today we are at 379 p.p.m.). That roughly translates into an average global warming of 2°C. While hard to achieve, and complicated by the need to take other greenhouse gases into account, the sooner such a target is agreed upon, the easier it is to achieve. So, somewhere between 379 and 450 p.p.m. may well be the safe zone.

This may mean more than a 2°C change for tropical forests, since change over land is higher than the global mean (because change over ocean is considerably less), and is regionally variable. Even 2°C is a very ambitious goal given the social/energy restructuring implied (Lackner, 2003). Hitting a greenhouse gas target of 450 p.p.m. implies a total transition from fossil fuels to renewable energy in the next several decades. Given that renewables currently account for about 13% of energy consumption (and 80% of that is fuelwood use that may not be sustainable as currently practiced) and increase in renewables is rising less quickly than rise in overall demand, the change required is far from incremental.

Yet, it is a change that may be of critical importance to tropical forests. Early modeling results indicate major range changes in tropical species due to future climate change (Ferreira de Siqueira and Peterson, 2003; Miles *et al.*, 2004). Other studies indicate that changes in the past may have been muted (Bush *et al.*, 2004), and there is great uncertainty about past change and no analog from the past for future magnitude and speed of changes expected in the future.

15.6 CONCLUSION

International agreements have the right targets in place to take the first, most important steps towards protecting tropical forests from climate change. The Convention on Biological Diversity (CBD) has targeted a measurable reduction in global biodiversity loss by 2010, which implies completion of the global protected areas network, its adequate funding, and significant reduction of destructive practices outside of protected areas. The Kyoto Protocol of the UNFCCC is now in place, which sets a framework for international cooperation in emission reduction. The UNFCCC itself targets avoiding climate change that would impair ecosystems' ability to adapt naturally. Even though this formulation is technically awkward, its intent is clear.

But, reality clashes very strongly with these goals—in tropical forests and many other systems: habitat loss continues; evidence is mounting that climate change is compounding the damage of habitat loss; and some systems may already be past natural ability to adapt (corals). What can biologists do? In tropical forests we can work to understand critical clues to the possible future effects of climate change. These include better understanding of past responses, better understanding of current species distributions and ecology, and analysis and modeling of responses to future climate change. Above all, we can work to rapidly incorporate the results of that research into improved conservation strategies, and to advocate the lowest possible atmospheric greenhouse gas stabilization levels.

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