INTERNATIONAL SUSTAINABILITY UNIT

TROPICAL FORESTS

A Review

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Contents

CLARENCE HOUSE

For many decades, I have been profoundly concerned about the state and future of the world's tropical forests. It remains my absolute conviction that all humanity and all creation would be deeply diminished if we were to lose these astonishing ecosystems. Indeed, I believe we simply cannot survive without them. After all, they are the vital organs, in this case the "lungs", of an essentially living, organic and integrated whole – our planet. There are no opportunities for transplants if they go wrong or we cause them irreparable damage by not caring for them. Our responsibilities as custodians of the Earth, and to current and future generations for its wise stewardship, compel us to act.

It is in this spirit that my International Sustainability Unit commissioned the report before you, 'Tropical Forests: A Review'. The purpose of the report is both ambitious and simple – to take stock of the condition of the world's tropical forests and of global efforts to protect them. The report draws on a large body of research and engagement with governments, companies, scientists and N.G.O.s. My hope is that it will be considered to be a helpful contribution to the debate in this vital year of international deliberations, and that it will provide an inspiration to the international community to redouble its efforts in support of forests over the decades ahead. For despite all that we have achieved, it is an alarming fact that rates of deforestation and degradation continue to rise, and that the underlying causes of this increase are set to become very much more acute…

A number of the findings in the report are, I think, particularly striking. The latest climate science demonstrates how important forests are for the mitigation of global climate change. The potential for greenhouse gas emissions mitigation from reducing deforestation, reducing degradation and pursuing forest landscape restoration is highly significant. Together, doing just these three things could play a major role in our efforts to meet the global obligation of keeping climate change to beneath a two degree rise in average global temperatures. And we can act on forests now, therefore buying much-needed time to enable the global transformation to a low carbon economy that places our cities and landscapes within a truly resilient and sustainable system.

But forests are not just about the climate change challenge, however vital and pressing that may be. They are also home to many thousands of indigenous and tribal peoples, some of whom remain uncontacted, such as in the Colombian Amazon which I had the privilege to visit last year, and to the countless other species with whom they have lived in a symbiotic relationship for thousands of years. There is a remarkable correlation between indigenous reserves and tropical forest conservation. Many millions more people depend directly on forests for their well-being and livelihoods. The report references recent illuminating work on the biodiversity and ecological interactions of tropical forests; on the role of forests in regional and global water cycles, on which so much of our food security in turn depends; and on how forests enhance our adaptive capacity and resilience and also reduce the risk of disasters. For all these reasons, and for the intrinsic value of forests which we have a duty to recognize and respect, there is a strong onus upon us to act.

Fortunately, and despite the scale of the challenges before us, the report also shows that there is growing local and international agreement on the action required to protect forests. This is just as well for we are, in effect, consuming the forests and, with them, the planet's ability to survive the blight of climate change. Each and every one of us has a vital role to play, whether as consumers, investors, managers or as those who are charged to agree and implement policies. And, equally, every country and institution has a role to play in addressing its forest footprint and the causes of forest loss, whether driven by biofuels policy, illegal deforestation and degradation, increasing global demand for beef, soya, leather, pulp and paper, sugar and wood, or mining, roads and infrastructure.

Ultimately, of course, there is a need to consume much less and to tread more lightly on the face of this planet; it is, after all, the only one we have, but we still perversely persist on including it in our throwaway society. This year's multilateral political settlement, culminating in the Sustainable Development Goals and at the U.N.F.C.C.C. in Paris in December, should lay the groundwork for that transformation to happen. For the world's forests, and all of the world's people who depend upon them (particularly many of the poorest people on Earth), this is perhaps the best opportunity to ensure the protection of the forests and therefore provide our species with a recognizable future.

It is, I think, becoming gradually understood that we need to treat the Earth as if it were a patient. It is one, I fear, that is in an increasingly critical condition and which requires intensive care. Given that the forests are in effect the planet's lungs, destroying them can surely only be an act of insane irresponsibility. It is not, after all, that we lack the technology, the money or the ability to safeguard their survival and, therefore, our own. Will, therefore, humanity, at the last, prove itself equal to the challenge and find the determination and the will to implement the solutions to this problem, from which, of course, many other positive benefits will arise? For, in the memorable words of Mahatma Gandhi: "What we are doing to the forests of the world is but a mirror reflection of what we are doing to ourselves and to one another."

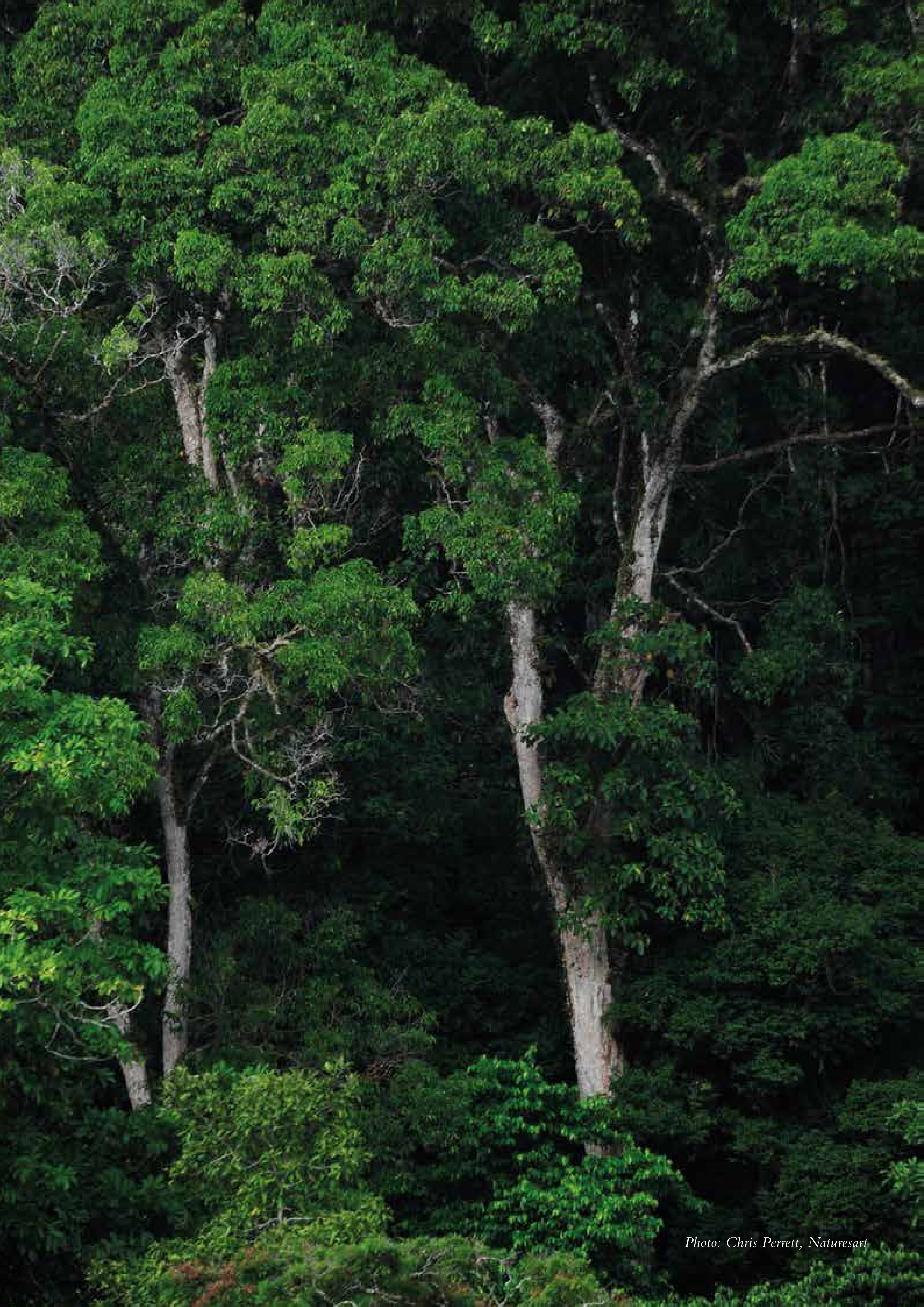


Photo: Chris Perrett, Naturesart

The ISU and its work on tropical forests

HRH The Prince of Wales established the International Sustainability Unit (ISU) in 2010 to facilitate consensus on how to resolve some of the key environmental challenges facing the world, such as food security, terrestrial and marine ecosystem resilience, the depletion of natural capital, and climate change.

The ISU builds on the work of The Prince's Rainforests Project (PRP), established in October 2007 to bolster efforts to reduce and eventually halt tropical deforestation, which led to donor fast start finance commitments of several billion dollars to reduce deforestation.

Recent ISU work on forests includes analysis and high level cross-sectoral convening in support of efforts to reduce deforestation in commodity supply chains; to enhance donor coordination on REDD+; to explore the economics of sustainable agro-ecological intensification in Brazil, Indonesia and West Africa; and to raise international awareness about the latest findings from tropical forest science.

Objectives of the report

This report seeks to provide a synthesis of the current state of knowledge on the world's tropical forests and an objective evaluation of policy responses intended to protect and nurture them. It aims to stimulate discussion within the policy communities of donor and tropical countries, companies involved in supply chains, academia, and NGOs. While not exhaustive, it draws on many recent reports, articles and peer-reviewed scientific papers, and widespread consultation with Governments, academics, the private sector and civil society.

Acknowledgments

The ISU wishes to express its deep gratitude to Bernard Mercer for his hard work, diligence and enthusiasm in preparing the report over recent months. We are also most grateful to Will Ashley-Cantello, Jim Baker, Erika Berenguer, Richard Betts, Jonah Busch, Robin Chazdon, William Cook, Chris Delgado, Christine Dragisic, Rupert Edwards, Sean Frisby, Toby Gardner, John Grace, Richard Houghton, James Jansen, Donna Lee, Ruben Lubowski, Connie McDermott, Melissa Pinfield, Stephen Rumsey, Neil Scotland, Frances Seymour, John Verdieck, and Mike Wolosin for their invaluable comments on the report.

In addition, we thank a long list of all those from around the world who contributed to our thinking and in discussion of the issues. The ISU would be glad to receive thoughts and responses to the report, and to correct errors of fact or interpretation: please send these to Beatriz Luraschi at the ISU, at beatriz.luraschi@royal.gsx.gov.uk.

Executive Summary

The latest climate change science demonstrates that, left unchecked, global warming presents 'severe, pervasive and irreversible consequences' for humanity and the planet. Climate change is principally driven by the burning of fossil fuels and by greenhouse gas emissions from deforestation, degradation and land use change. As a result of the latter, the earth's natural capital is continuing to be badly degraded – water, soils, air, forests. Within the global forest estate, the worsening condition of tropical forests remains a matter of particular concern.

Despite success in reducing forest loss in some countries, there are no signs yet that overall rates of deforestation or degradation are decreasing: a major 2013 paper (for 2000-2012) reports a year on year increase in the area deforested in the tropics of 200,000 hectares a year. And, at the overall level, the annual area lost remains very significant, c.8.5 million hectares.[1] For degradation, a number of regional studies report extensive and alarming losses (see **Section 4**).

The global warming consequences – from greenhouse gas emissions and a reduction in the capacity of forests to absorb and store carbon – are grave, and likely to be especially acute in tropical regions themselves. Forest loss also leads to the breakdown of critical ecosystem services, such as water provision, and interferes with regional climatic patterns, with serious knock-on effects for agriculture and food security.

The drivers of deforestation and degradation are dynamic and inter-linked. Attempts to deal with them have tended to be specific, yet because of the many variables and feedback loops, they need to be addressed holistically. In particular, it can be argued that the causes and consequences of tropical forest degradation have been given too little attention, with the science now pointing toward degradation being a very significant component both of greenhouse gas emissions and the weakening of forest ecosystems.

Solutions such as REDD+ need to reflect these realities, but although much progress has been made, this has not in the main yet been at the spatial level where action matters most: the landscape. With respect to finance, progress toward a pipeline of fundable forest protection projects and programmes has not been matched by measures to stimulate demand. As a result, a significant funding problem exists, compounded by long-term uncertainty about how REDD+ will be financed at scale. The New Climate Economy report estimates that donor countries need to double their contributions if the gap between current and required finance is to be bridged. But increased pledges and disbursement should not be seen as a panacea. The effectiveness of the mechanisms and instruments which deliver REDD+ funding is equally critical, as is the imperative for renewed ambition – from tropical forest countries and the international community alike – to achieve success at scale.

The enabling conditions for the enduring conservation and wise stewardship of forests go beyond the scope of REDD+, although many of the key factors are being addressed within this framework. Security of land tenure and effective land-use planning are essential prerequisites, which in turn rest on recognition and respect for rights, and strong and accessible institutions and processes. Over-arching conditions include good governance and economic growth, and the existence of mechanisms and markets which provide investors (including governmental funders) with confidence that positive environmental and social outcomes can be obtained effectively and legally. Collective endeavour and a sense of shared responsibility are needed for success to be achieved, with support and leadership at the highest level from Governments, companies and civil society.

Climate mitigation and forest science

Tropical deforestation remains a major driver of global warming, emitting 0.8-0.9 Gigatonnes of Carbon (GtC) annually, equating to 8% of global carbon emissions. Less widely recognised, tropical forest degradation accounts for a further 0.6–1.5 GtC per annum, equating to a range of 6-14% of all anthropogenic carbon releases (or 10-14% if estimates are based on the recent noteworthy studies by Grace *et al.* and Houghton, see **Table 3, Section 2**). In aggregate, the two sources may account for 14-21% of all carbon emissions, perhaps higher still when tropical peatlands and mangroves are included.

On the other side of the tropical forest carbon ledger, current sequestration of atmospheric CO_2 is also significant, drawing down 1.2-1.8GtC a year. The convention in greenhouse gas accounting is to 'offset' these removals against tropical forest emissions; that approach is arguably insufficient, for two reasons. Recent findings on the importance of forest protection as a means to safeguard continuing sequestration indicate that a significant proportion of CO_2 absorption occurs as a result of human agency. Additionally, the net accounting approach distracts attention from the reality of much higher gross emissions.

These considerations provide the rationale for a different accounting approach, in which the data are combined. Actions to reduce carbon emissions from deforestation and degradation, and to safeguard existing tropical forest sequestration could, in aggregate, contribute as much as 24-33%* (3.45-3.86GtC) of all carbon mitigation (12.05-12.46GtC); perhaps more if other variables are taken into account (see **Table 6, Section 2**).

The wide ranges for degradation and sequestration reflect continuing uncertainties, and the data are best seen as indicative of the significance of these factors, pending further research. None the less, the benefits of considering the mitigation and sequestration potential of tropical forests in the round seem clear: 24-33% is a highly significant component of the overall carbon mitigation goal, underscoring the critical importance of tropical forests within the climate challenge. The inter-connectedness of the factors at play means that continuing deforestation and degradation will produce a double loss (CO_2 emissions and a lower level of CO_2 absorption), while success in reducing them will result in a win-win outcome (lower CO_2 emissions, more sequestration).

Forest ecology and science

A burst of new science since 2000 has enriched our understanding of how tropical forests (including peat and mangrove forests) maintain and renew themselves through an array of ecological and environmental interactions. The findings highlight how logging, defaunation and other disturbances disrupt or extinguish such interactions, impair ecosystem functioning, and lead to weakened forest resilience. Resultant impacts on the carbon and water cycles are of fundamental concern, as these cycles drive the services on which humanity is dependent – including rainfall generation, water supply for agriculture, CO_2 absorption, and carbon storage. There is a case for the rapid incorporation of current ecological understanding into global forest policy and forestry practice.

The drivers of deforestation and degradation

The drivers of deforestation and degradation vary across the tropics and include commercial and smallholder agriculture, mining, roads and infrastructure, legal and illegal logging, and defaunation. They are also inter-connected and dynamic, implying the need to address them holistically, at all levels of governance. The challenges are compounded by difficulties relating to the valuation of the services forests provide, and a range of definitional issues. Projected increases in global demand for wood products and agricultural commodities will significantly increase pressure on tropical forests over the next few decades.

* The percentages attributable to deforestation and degradation within the 24-33% range (see Table 6) are different from those shown above (and in Table 3). This is because they are percentages of a larger total, which includes sequestration in the combined estimate.

Policy responses: REDD+

Launched in 2005, REDD+ is seen by many as the best hope for tropical forest protection. While the scheme is yet to become fully operational, more progress has been made to date than is generally recognised, particularly through the development of REDD+ technical capital and capacity building. A target-based, landscape-scale and jurisdictional approach could deliver effective outcomes that meet REDD+ objectives. Synergies between REDD+, supply chain and restoration initiatives could improve outcomes and catalyse greater finance flows. The potential roles of a range of mechanisms and instruments, including jurisdictional REDD+ approaches (including bonds), public sector subsidy models (akin to Feed-In Tariffs for renewable energy) and other concessional finance approaches hold promise as options for stimulating demand, which remains the over-arching REDD+ challenge.

Supply chains, restoration and other efforts

Efforts to develop deforestation-free supply chains are making significant progress, but need to move more rapidly from the commitment to the implementation phase. Other supply chain priorities include expansion beyond soy, beef, palm oil and timber, and the identification of alternative lands for production that meet rigorous carbon, biodiversity and social criteria. For restoration, the key question relates to purposes: what should degraded forest landscapes be restored to? There is a need for quantified targets to ensure that one objective is not achieved at the expense of others.

Care needs to be taken that the climate mitigation function of forests and the provision of other ecosystem services are not marginalised within restoration initiatives. For conservation, the under-valuation of carbon and biodiversity services provided by protected areas remains a serious concern; the eligibility of Protected Areas for REDD+ funding should be revisited. A further priority is the urgent need to devise policy responses that address the issue of defaunation as an agent of forest degradation.

Sustainable forest management and global wood demand

The role of selective logging within forestry could valuably be re-assessed in the light of new findings on its role as a driver of degradation. The expansion of socially and environmentally sustainable tropical plantation capacity could help to meet rising wood demand, reduce pressure on natural forests and enhance livelihoods through community plantation schemes. A certified degradation-free supply chain concept could be developed for plantation outputs.

Enabling conditions

Securing the right enabling conditions for wise tropical forest management is a vital but complex challenge. The key conditions include better land use planning, land tenure reform, strong governance, community rights and livelihoods, effective management, donor and investor confidence in forest financing schemes, and the effective utilisation of technology.

International and regional efforts

Recent international initiatives, particularly The New York Declaration on Forests, The Bonn Challenge and The Lima Challenge, are raising the level of ambition and catalysing action. The UN Sustainable Development Goals, which are likely to include a goal encompassing forests, and the new Inter-Governmental Panel on Ecosystem Services, provide further opportunities to prioritise tropical forests across the UN system. Initiatives such as the Governors' Climate and Forests Task Force and the Three Basins Initiative indicate the importance and value of regional action. And forests, REDD+ and land use ought to be a central feature of the forthcoming climate agreement in Paris in December 2015.

Where we are

The original thought behind the writing of this report was to provide a quick snapshot of the state of progress on preserving tropical forests, to acknowledge recent positive developments and to see if anything might be identified to fill the gaps. As is evident, it has become a rather broader document than anticipated. Perhaps the starkest conclusion is that, despite all that has been done, it is still not enough and the rate of deforestation is still increasing. In addition, it is apparent that while the focus on the drivers of deforestation and degradation has widened, it is not yet broad enough to encompass adequately the systemic and interconnected nature of the problem. This lack of a truly systemic approach creates a real challenge, as it appears improbable that success can be achieved unless the solutions proffered mirror the complexity of the social, economic and ecological interdependencies which form the basis of the forests' existence. Perhaps, though, the clearest message is that these ecosystems, which are essential for our survival, are only salvageable if there is a real determination by both the public and private sectors to take the difficult policy, economic and financial decisions required to ensure appropriate governance and management. Evidently, this would seem not yet to be the case.

Early morning in a primary rainforest. Photo © Mattias Klum

1 The current state of knowledge on tropical forests

Summary points

- Tropical forest science has advanced considerably since 2000, catalysed by innovations in remote sensing technologies;
- Improved media coverage is helping to disseminate findings;
- These point to the deteriorating condition of many remaining forests;
- Improved technology is providing more precise information on the scale, locations and drivers of deforestation and degradation.

Our understanding of tropical forests is far better now than a decade ago.[2] There are maps which delineate many of the key components (forest extent, carbon stocks, emissions and sequestration data, biodiversity distribution, human populations, roads and other drivers of deforestation and forest degradation) at levels of accuracy and precision that were previously unavailable.

Science has also significantly improved available knowledge on two other fronts: the ecological and environmental interactions which underpin forest resilience and renewal (e.g. new findings on the water cycle, and the role of seed dispersing fauna); and the opportunity to restore tropical forests at large-scale. Nevertheless, our understanding remains imperfect. Achieving a balanced view of the array of factors sustaining or destroying forests remains challenging, with different narratives promoting different perspectives.

Examples include the relative weighting (often varying significantly from region to region) that is attributed to the range of drivers of forest loss and damage (e.g. palm oil, soy, beef, timber, wood pulp, mining, roads, charcoal) and the wide range of views on the efficacy of specific interventions (e.g. sustainable forest management, community forestry, protected areas). Assessments of the state of tropical forests thus need to be continually reviewed in light of new information and experience.

The past and present extent of tropical forests

Forests once occupied more than 7.4 billion hectares – just under half of the earth's land surface (see **Table 1**). Those in the tropics were by far the largest, covering 3.6 billion hectares. Starting with the controlled use of fire c.500,000-300,000 years ago, the long history of human conversion and modification of forests has radically reduced their extent. More than 2 billion hectares have been completely deforested (a quarter each from temperate and sub-tropical regions, a half from the tropics) to make way for croplands, pasture, cities and other settlements, roads and other infrastructure.[3]

In the tropical world, the forests that remain are still vast, covering 2.5 billion hectares, but deforestation continues apace, with c.90 million hectares lost in the decade from 2000-2010.[4] In that period, the greatest losses were in the Amazon Basin, though deforestation was also rapid and widespread in south-east Asia and parts of tropical Africa.[5] One study (for the period 2000-2012) estimates that the rate of tropical forest loss from deforestation is still increasing, by 200,000 hectares per year.[6,7]

At the country level, understanding deforestation rates of loss and trends is constrained by several factors: results vary widely as a function of the time-frames and geographic criteria employed; land-use is dynamic, not static (and forests can be cleared very quickly); and there is a lack of integration and calibration for the range of datasets.[8] The losses are also more widespread than is sometimes assumed: FAO estimates for 2005-2010 show that 2.8 million hectares were deforested in Brazil and Indonesia, but a further 4.2 million hectares were lost, in aggregate, from 25 other tropical countries.[9]

Table 1: Past and current forest area by ecoregion

Ecoregion	Past area	Deforested		Current area	
Boreal	1,425	-42	-3%	1,383	97%
Temperate	1,299	-518	-40%	781	60%
Sub-tropical	984	-450	-46%	534	54%
Tropical	3,646	-1,055	-29%	2,591	71%
Desert and Polar	64	-13	-20%	51	80%
Total	**7,419**	**-2,078**	**-28%**	**5,341**	**72%**

Source: Adapted from *A World of Opportunity for Forest and Landscape Restoration*. 2011. World Resources Institute.[10]

Notes: area data are in millions of hectares. Percentage data are relative to past area.

The current condition of tropical forests

Until recently, information on the condition of tropical forests lagged well behind the data on forest extent. Work by the World Resources Institute and others is beginning to rectify this at the global level, with current findings indicating that, of still standing tropical forests, 46% are fragmented, 30% are degraded, and only 24% are in a reasonably intact (mature or primary) state (see **Table 2**). A key next step is to integrate reporting on forest condition into regional and country level assessments, (which at present largely focus on deforestation data).

Table 2: The state of current forests

Ecoregion	Intact		Fragmented		Degraded	
Boreal	431	31%	744	54%	208	15%
Temperate	42	5%	493	63%	246	31%
Sub-tropical	9	2%	311	58%	214	40%
Tropical	616	24%	1,194	46%	781	30%
Desert and Polar	10	20%	40	78%	1	2%
Total	**1,108**	**21%**	**2,783**	**52%**	**1,450**	**27%**

Source: Adapted from *A World of Opportunity for Forest and Landscape Restoration*. 2011. World Resources Institute.

Notes: area data are in millions of hectares. Percentage data are relative to total current area.

Recent developments in tropical forest science and analysis

Many hundreds of recent scientific papers chronicle changes to the status of forests in impressive detail. To note just a few of the salient findings:

- A loss of 6 million hectares of primary forest was recorded in Indonesia between 2000 and 2012, with 840,000 hectares deforested in the final year of that period, more than the 460,000 hectares lost in Brazil in 2012;[11]
- The leading drivers of deforestation in Indonesia (2000-2010) were found by another study to be fibre (pulp and paper) production (1.9 million hectares), logging (1.8 million hectares)and palm oil (1 million hectares);[12]
- Significant increases in the rates of deforestation and forest degradation occurred (2000-2010) in the Democratic Republic of Congo;[13]
- Sarawak and Sabah in Malaysia have experienced massive (and previously undocumented) forest degradation across 80% of their land surfaces over the last two decades;[14]

- Peru's forests are increasingly under threat from a range of pressures, including timber extraction, particularly from illegal logging abuses of the legal concessions system,[15] oil palm plantations (72% of new plantations expanded into forested areas),[16] and gold mining (a 400% increase between 1999-2012);[17]
- Logging (and related understorey fires) are significantly lowering forest carbon stocks and resilience across large areas of the Brazilian Amazon, as well as releasing emissions up to 40% as high as those from deforestation;[18]
- The biodiversity of tropical forests is also under great pressure. A range of new studies have reported severe declines (including local extirpation) in the populations of small and large mammals,[19,20] (with several new papers on the rapid decrease in elephant numbers).[21,22,23] One estimate indicates that population levels (abundance) are falling sharply across many taxa – by as much as 25% for mammals and 45% for invertebrates.[24]

Such assessments and disclosures are the tip of an informational iceberg, enriching our understanding of the scale, nature, location and consequences of forest loss and damage, and signposting how and where positive outcomes can most readily be achieved. The use of current knowledge to drive both policy formulation and delivery is essential if wise stewardship of the tropical forest estate is to be achieved.

The role of technology

Much of the new science and analysis is underpinned by advances and innovations in technology, from satellite and airborne-based optical, radar and lidar observation to the use of hand-held devices in ground-level monitoring. Several recent studies[25] highlight the extent to which accuracy is rapidly increasing, with knowledge improving on effective combinations, processes and approaches.[26] In some cases this is revising prior understanding; an example is a recent study which found that forest carbon densities in Amazonian plots vary by more than 25% from satellite estimates, indicating the need for geographically specific carbon stock estimates that take account of variations.[27]

In overall terms, the advances and innovations are reducing the ranges of uncertainty which have constrained action in the past, and contributed to insufficient focus on forest degradation.[28] Looking forward, the production of national level forest cover and condition mapping[29] will provide the basis for policies that are better attuned to physical realities.

Definitional issues

While the extent and quality of scientific data on forests have improved markedly, several definitional issues continue to hamper the ready interpretation of findings, and their application to policy. These include the absence of a clear distinction between natural and planted forests, and the continuing failure to incorporate quantification (and clear definition) of the level of degradation within assessments of standing forests (see **Section 4** for further exploration of these issues).

Dissemination

In parallel to the increasing depth of information is a step change in its public availability, principally through the following three channels.

Open access science

In the pre-internet era, scientific information on tropical forests was essentially the preserve of scientists. Policy makers and the interested public faced significant challenges accessing and interpreting data, with consequent lack of clarity on trends, threats and effective options for action. Since 2000, the drive to put science into the public domain (led by the PLOS initiative)[30] is improving accessibility. Services such as Science Daily[31] provide vernacular summaries of new papers and interviews with the scientific authors, and mainstream media provide links to the science via their online platforms.

Publicly available online tropical forest observation

Although the production of remote sensing imagery began when Landsat 1 went into orbit in 1972, free and interactive access to satellite-based tropical forest maps only became available in February 2014, with the launch of Global Forest Watch.[32] The GFW-based report on the loss of 'intact forest landscapes' since 2000 is an illustration of how knowledge of fundamental changes within tropical forests can rapidly be brought into the public domain.[33]

Improved media coverage

Most attention has until recently been heavily focused on the Amazon Basin and Indonesia, for valid reasons. It is also important, however, to understand trends elsewhere, not least those within the 40-60 other tropical countries that retain significant forest areas.[34] Such information is becoming increasingly available through reporting by Mongabay, forestcarbonportal.com, Ecosystems Marketplace, the Reuters Foundation, CIFOR, the Center for Global Development and others.

The many stories published during 2014 included coverage of: the logging crisis in Myanmar;[35] efforts to save a Ugandan reserve in the midst of massive deforestation;[36] rebuilding Kissama, war-torn Angola's only national park;[37] threats to biodiversity in the Philippines;[38] intensification of forest loss in Peru;[39] the destruction of the Chaco forests in Paraguay;[40] deforesting of protected areas in Nicaragua;[41] and threats to the Ndoki forest in Republic of Congo.[42] These narratives help counter the tendency towards abstraction in debates over tropical forest protection, by focusing attention on the people and wildlife that depend upon them. There has also been an increase in the publication of analytical forest policy critiques (including on the supply chain and zero-net deforestation initiatives).[43]

Joining up tropical forest science and analysis

Tropical forest science and analysis draws on many disciplines, including economics, land-use planning, and various social sciences as well as ecology, biodiversity conservation and climate modelling. Many of the findings are the product of specialisation, and more secondary research that synthesises results and produces reliable overviews would be extremely helpful to complement individual advances in knowledge. Without such clarity, policy formulation may be deprived of important research insights.

Photo: Chris Perrett, Naturesart

2 Tropical forests and climate mitigation

Summary points

- Tropical deforestation remains a major driver of global warming, accounting for c.8% of annual anthropogenic carbon emissions, whilst the less widely recognised emissions from tropical forest degradation account for a further 6-14%;
- In aggregate, the two sources may thus account for as much as 21% of all carbon emissions, perhaps higher still when emissions from tropical peatlands and mangroves are included;
- The under-recognition of the scale of emissions from forest degradation is reflected in the low prioritisation of actions to address degradation in mitigation strategies;
- On the other side of the forest carbon ledger, current sequestration of atmospheric CO_2 (1.2-1.8GtC per annum) is also significant, indicating the need to safeguard primary and recovering forests;
- The tropical forest sink could absorb larger volumes of CO_2 if trends on deforestation and degradation were to be reversed;
- A new strategy on these lines could contribute between 24-33% of all carbon mitigation, perhaps more if additional sequestration is achieved, and other variables are taken into account.

New findings from recent science and spatial analysis are leading to re-evaluations of the scale of emissions from tropical deforestation and degradation (the *source* function), and are also highlighting the potential for the removal of carbon dioxide from the atmosphere through restoration and reforestation (the *sink* function).

Emissions from tropical deforestation

Deforestation results in 0.8GtC – 0.9GtC of emissions per annum – losses which are largely irreversible. The global deforestation rate remains alarmingly high, at circa 8.5 million hectares a year, and continues to rise.

Reducing or halting tropical deforestation – the complete clearance of an area of forest and its subsequent conversion to cropland, pasture, or other land-uses – is regarded by many as the highest priority within efforts to stem carbon emissions from tropical forests. The focus has increasingly been on curbing forest conversion for commercial agriculture, which a recent study identified as the driver of 71% of all tropical deforestation between 2000 and 2012[44] (see **Section 4**).

Where forest degradation (the loss of some trees within a forest as a result of logging, fires, mining, roads and other damaging human activities) occurs, recovery is often possible – given sufficient time and protection – through regrowth; but most new 21st century deforestation losses are likely to be irreversible, for several reasons. If deforestation is followed by conversion to cropland or pasture, tree seed stores in soils and ground litter are likely to be lost; the extent to which 'new' forests can arise via natural regeneration on abandoned agricultural lands varies considerably as a consequence of this and other environmental and ecological factors (e.g. presence of seed dispersers in the region, water availability).

Further considerations include the ongoing requirement for increased food supplies, implying that large-scale abandonment of agriculture is highly unlikely in most tropical regions, and the costs of re-planting as a barrier to extensive reforestation.

From a climate perspective, the case for continuing concerted action is underpinned by the scale of emissions from clearance of undisturbed natural tropical forest. These are immediate and large: as much as 220 tons of carbon per hectare (800 tons of CO_2).[45] Extrapolating actual pan-tropical annual deforestation loss from this data [46] (but allowing for the wide variation in carbon stocks, and discounting for natural factors, see *gross vs. net accounting*, below)[47] produces annual emissions estimates (see **Table 3**) of 0.8GtC to 0.9GtC.[48]

The case for amplifying efforts to curb tropical deforestation is underscored by the ongoing and increasing scale of loss: the total area cleared annually is estimated at c.8.5 million hectares (for 2000-2012) in a major 2013 paper, with losses accelerating at a rate of 200,000 hectares a year.[49] This is despite the 70% reduction in Brazil's[50] deforestation emissions since 2004, a fall that has been attributed to a range of factors, including strong political leadership, more effective forest protection through law enforcement,

Table 3: Estimates of annual carbon emissions from tropical forests

	Harris *et al*[(b)]		Grace *et al*[(c)]		Houghton[(d)]	
	GtC	% of all emissions	GtC	% of all emissions	GtC	% of all emissions
Tropical deforestation	0.80	8.00%	0.90	8.49%	0.81	7.44%
Tropical forest degradation	0.60	6.00%	1.10	10.38%	1.47	13.51%
Deforestation *plus* degradation	**1.40**	**14.00%**	**2.00**	**18.87%**	**2.28**	**20.96%**
Fossil fuels and cement production[(a)]	8.60	86.00%	8.60	81.13%	8.60	79.04%
Total emissions[(d)]	**10.00**		**10.60**		**10.88**	

Sources: (a) Le Quere, C., *et al*. 2013. *Global Carbon Budget 2013*. Earth Syst. Sci. Data Discuss., 6, 689–760 (averaged for 2003–2012); (b) Harris, N., *et al*. 2012. *Progress Toward a Consensus on Carbon Emissions from Deforestation*. Winrock International; (c) Grace, J., et al. 2014. *Perturbations in the carbon budget of the tropics*. Global Change Biology (data from 2005–2010); (b) Houghton, R.A. 2013. *The emissions of carbon from deforestation and degradation in the tropics: past trends and future potential* (data from 2000–2005). Carbon Management. (d) emissions from other land-uses are are included on a net basis (see IPCC AR5, chapter 11, pp16–22)

interventions in soy and beef supply chains, restrictions on access to credit, and the management of indigenous reserves and protected areas.[51] In many other countries deforestation has risen, with Indonesia recording the highest increase in area terms.[52]

Emissions from tropical forest degradation

Advances in remote sensing and on the ground observations have improved the estimation of carbon emissions from tropical forest degradation. While many uncertainties remain, recent studies estimate that such degradation accounts for 6-14% of all annual anthropogenic carbon emissions. A commensurate policy response is called for.

Most of the studies referenced above also provide global estimates for emissions from tropical forest degradation, but the range is much wider: from 0.6GtC – 1.47GtC, implying total emissions (deforestation plus degradation) of 1.4GtC – 2.28GtC (see **Table 3**). One paper suggests the upper figure may be as high as 2.9GtC.[53] Uncertainty derives from several factors, including lack of precision in remote sensing, difficulties in calculating emissions from widely differing levels of forest damage, and from lack of uniformity in the categorisation of the range of causes of degradation.

Studies draw on one or more of three sources: national inventories reported to the FAO; forest biomass results derived from research plots; and data obtained from satellite remote sensing. Each has limitations.[54] The reliability and consistency of inventories is often questioned; plots may not be representative, leading to potentially large margins of error when extrapolated to scale; and the three modes of data acquisition by satellites (optical, radar, lidar) produce varying results.[55]

Though there is broad agreement that the drivers of degradation emissions include commercial harvest (logging), fuelwood harvest (including for charcoal), shifting cultivation (swidden agriculture), disturbance of soils, and burning, few studies use exactly the same categories (see **Table 4**), with much lumping and splitting occurring.

Two further challenges relate to the role of tropical peatland and mangrove forests as sources. Some studies include peatland emissions under the degradation heading, while others exclude them from consideration altogether; and emissions from mangroves seem to lie outside terrestrial modelling, perhaps because they are often seen as components of marine or freshwater ecosystems. For the moment, the case for including both peatland and mangrove emissions under degradation is strong, in the absence of an alternative emissions category (see **Section 4, Definitional challenges**).

The effect of these complications is twofold: the number of variables leads to wide ranges (high uncertainty), and the complexities make comparisons between studies difficult, especially for policy-makers.[56] However, there is a danger that these data and definitional challenges obscure our understanding

Table 4: Sources of annual tropical forest carbon emissions

	Grace *et al*[(a)]		**Houghton[(b)]**	
	GtC	**% of total**	**GtC**	**% of total**
Peat burn	0.54	26.9%		
Harvest	0.36	17.9%		
Degradation	0.21	10.4%		
Deforestation	0.90	44.8%	0.81	35.5%
Industrial wood harvest			0.45	19.7%
Fuelwood harvest			0.23	10.1%
Soils			0.15	6.6%
Shifting cultivation			0.64	28.1%
Total	**2.01**		**2.28**	

Sources: (a) Grace, J., *et al*. 2014. *Perturbations in the carbon budget of the tropics*. Global Change Biology (data from 2005–2010); (b) Houghton, R.A. 2013. *The emissions of carbon from deforestation and degradation in the tropics: past trends and future potential* (data from 2000–2005). Carbon Management.

of the impacts of degradation, when at a broad level these are clear: logging and other extractions and disturbances in mineral, peat and mangrove forests across the tropics are weakening forest structure and resilience, and triggering significant emissions.

A range of recent regional and country-based studies indicate that as evaluations of the impacts of degradation become more precise, estimates are reporting significant resulting emissions. For example, a large-scale field assessment of carbon stocks in the Brazilian Amazon (based on 225 plots, with an aggregate area of 3 million hectares) found that degradation in human-modified primary forests was responsible for as much as 30% of all forest emissions in the area studied.[57] Another study, utilising high resolution remote sensing (1999-2002 data) found that emissions from selective logging in a 266 million hectare swathe of the Brazilian Amazon were 15-19% higher than those reported for deforestation alone.[58]

Elsewhere, research on the forests of Sabah and Sarawak (Malaysian Borneo) found that nearly 80% of the land surface was impacted by previously undocumented, high-impact logging or clearing operations (1990-2009).[59] Looking at the broader picture, one paper concludes that the average of emissions from logging in nine countries is equivalent to 12% of deforestation emissions. However, the range reported (6%–68%)[60] is wide, indicating that the impacts of degradation (and consequent emissions) are very high in some tropical countries.

When taken together with the pan-tropical modelling undertaken by Grace, Houghton and others, these studies indicate that degradation is now estimated as the source of at least 30% – and perhaps as much as 50% – of all emissions from tropical forests, with legal and illegal logging as the key drivers (see **Section 4**). This is a significantly higher proportion than was recognised a decade ago, and implies a need to re-visit the assumption that if deforestation can be curbed, tropical forest emissions will fall to safe levels.

Emissions from tropical deforestation and forest degradation combined

In aggregate, tropical deforestation and degradation account for 14-21% of all anthropogenic carbon emissions.

The evidence from recent studies indicates that 14-21% of all anthropogenic carbon emissions are attributable to tropical deforestation and degradation (see **Table 3**). There appear to be three main factors at play in explaining why this represents a higher proportion than is sometimes reported. These are: emissions from deforestation may not have trended downwards as much as is generally assumed; emissions from degradation may have been accelerating over the last decade, as well as having been previously under-counted; and emissions from sources where there is a high degree of uncertainty (such as cutting of tropical peatland and mangrove forests and some aspects of forest degradation) have probably been under-stated.[61] More broadly, the seeming disparity between past and present estimates is a function of net accounting (see below).

Tropical forest sequestration

Interest in sequestration has surged in recent years, both in the scientific and policy communities. Recent studies suggest that the existing level of CO_2 absorption within primary and recovering tropical forests is providing a vital mitigation service, removing 1.2-1.8GtC annually, and thus accounting for 10-15% of carbon mitigation potential. Sequestration would increase if deforestation and degradation were reduced.

Estimates of removals of atmospheric CO_2 (sequestration) through growth in tropical forests (the *sink* function) are found in all major studies: but, in general, these do not attribute the results of sequestration to particular causes. While these are understood in the broad sense, data to enable analysis of sub-categories were not available until recently. The estimates by Grace and Houghton (see **Table 5**) indicate that this challenge is beginning to be addressed; further contributions along these lines are likely in the near future as research builds on the Hansen map[62] and the lidar[63] assessments carried out by Greg Asner and others.[64]

Table 5: Analyses of current annual tropical forest carbon sequestration

	Grace *et al*[(a)]		**Houghton[(b)]**	
	GtC	**% of total**	**GtC**	**% of total**
Secondary forest regrowth	1.14	61.6%		
Primary forest growth	0.47	25.4%		
Net sink additions from plantations	0.24	13.0%		
Regrowth after industrial wood harvest			0.45	38.3%
Regrowth after fuelwood harvest			0.15	12.5%
Regrowth after shifting cultivation			0.56	47.9%
Afforestation			0.02	1.3%
Total	**1.85**		**1.17**	

Sources: (a) Grace, J., *et al*. 2014. *Perturbations in the carbon budget of the tropics*. Global Change Biology (data from 2005–2010); (b) Houghton, R.A. 2013. *The emissions of carbon from deforestation and degradation in the tropics: past trends and future potential* (data from 2000–2005). Carbon Management.

Forest fire haze over Singapore. Photo: NASA Earth Observatory

Pending further analyses, sequestration can be categorised under four principal headings: reforestation (tree planting); continuing growth in primary forests; regeneration of secondary forests; and forest regrowth on abandoned (previously farmed) lands. The first is anthropogenic, but the other three are usually treated as non-anthropogenic: changes in the balance of *source* and *sink* functions occurring as a result of natural processes and thus not attributable to human intervention. Perhaps because of this the natural regeneration of tropical forests (and vegetation on other lands) has not been seen, until recently, as a significant mitigation option.

Perspectives are now changing, and interest in restoration potential – for example, schemes to prevent further logging in degraded forests as an intervention designed to rebuild prior levels of carbon storage – has led to (and been stimulated by) an emerging body of research that seeks to quantify climate mitigation gains from removals. In principle, active restoration management for mitigation can contribute to the *'enhancement of forest carbon stocks'* goal within the REDD+ framework.

Several studies estimate current annual sequestration in tropical forests in a range of 1.2GtC – 1.8GtC,[65] with the potential for much higher levels, if management of tropical forests prioritised and assisted recovery and reforestation. One recent modelling exercise sees the cumulative potential of 21st century land-based mitigation at 100GtC (additional carbon dioxide removals through reforestation from 2031-2080),[66] an estimate that correlates with other studies.[67,68] Sequestration at this level could reduce existing CO_2 concentrations by almost 50ppm, a significant step toward climate safety.

At first sight this seems unrealistic, but some simple maths can shed light on such estimates. There is general consensus in the forest carbon literature that many recovering and primary forests can absorb an average of 2 tons of carbon per hectare, per year;[69] and on this basis, if all 781 million hectares[70] of degraded tropical forests (see **Table 2**) were fully protected and thus enabled to regenerate, they would remove 1.5 GtC per annum.[71] Over the 35 years to 2050 this would reduce greenhouse gas concentrations by 25ppm.[72] This is broadly in line with the Houghton study which frames the task ahead as increasing current gross uptake to 2-3GtC through measures that incentivise forest recovery for increased sequestration, and ongoing protection of the existing tropical forest CO_2 absorption capacity.[73]

Mitigation from avoided emissions *plus* sequestration

The potential CO_2 mitigation contribution resulting from avoiding emissions from deforestation and degradation, and maintaining existing levels of sequestration could amount to as much as 24-33% of all anthropogenic carbon mitigation.

Data from the Grace *et al* and Houghton papers (see **Table 6**) on emissions from deforestation and degradation and current sequestration produces a combined tropical forest mitigation total of nearly 3.45-3.86GtC per annum. If the lowest and highest figures for each category are drawn from the two studies, the tropical forest contribution to all carbon mitigation is in a range of 24-33%.[74]

In arriving at this figure, current sequestration is taken to include ongoing CO_2 absorption within primary forests, and already degraded forests that are recovering from logging and other disturbances. It is also assumed that current sequestration would increase if deforestation and degradation were reduced, with the implication being that tackling the two emissions sources is the principal route to achieving more CO_2 absorption.

The potential increase in the volume of absorption could be higher still. Houghton estimates annual additional sequestration (from measures to protect tropical forests from further disturbances, and from reforestation) at 1.55GtC. If this were to occur, tropical forest mitigation as a proportion of overall carbon mitigation could rise to 36% of the total. However, given the many uncertainties, this report excludes potential additional sequestration from its scope.

Table 6: combined annual tropical forest carbon mitigation potential

	Grace *et al*[a]			Houghton[b]		
	GtC	% of tropical forest mitigation	% of total mitigation	GtC	% of tropical forest mitigation	% of total mitigation
Avoiding deforestation	0.90	23.32%	7.22%	0.81	23.48%	6.72%
Avoiding degradation	1.11	28.76%	8.91%	1.47	42.61%	12.20%
Safeguarding sequestration	1.85	47.93%	14.85%	1.17	33.91%	9.71%
Combined tropical forest mitigation potential	**3.86**		**30.98%**	**3.45**		**28.63%**
Fossil fuel and cement mitigation potential[c]	8.60		69.02%	8.60		71.37%
Total carbon mitigation potential	**12.46**			**12.05**		

Sources: (a) Grace, J., *et al*. 2014. *Perturbations in the carbon budget of the tropics*. Global Change Biology (data from 2005–2010); (b) Houghton, R.A. 2013. *The emissions of carbon from deforestation and degradation in the tropics: past trends and future potential* (data from 2000–2005). Carbon Management; (c) Le Quere, C., *et al*. 2013. *Global Carbon Budget 2013*. Earth Syst. Sci. Data Discuss., 6, 689–760 (averaged for 2003–2012).

There is much to question and further develop in this new perspective. For example, it can be argued that current tropical forest sequestration should be subtracted because it is occurring naturally. On the other hand, some proportion of sequestration is occurring in tropical forests that are being protected by human agency to a greater or lesser extent (e.g. in protected areas, and via reforestation). It is also helpful to avoid compartmentalisation, as the three mitigation pathways are inter-connected: continuing deforestation and degradation erode the forest base that is achieving sequestration;[75] curbing these activities opens the prospect of additional recovery.

While recognising that uncertainties remain, the data clearly point to the need for a re-assessment of policy and action. At present, most responses focus on halting or slowing tropical deforestation, and given that most 21st century deforestation will effectively be irreversible (as explored in

Section 2), this should continue to be the leading priority. But in parallel, far greater attention needs to be given to halting and reversing degradation, recognising that the potential mitigation gains from such action could be as great as those from addressing deforestation.

The findings also bring fresh perspectives to bear on the proximate causes of both degradation and sequestration. The analysis presented in **Section 4** indicates that logging is the principal degradation driver, and that timber extractions are accelerating across the tropics. Some signposting of possible responses is given in **Section 9**. Every hectare of tropical forest that is lost to deforestation or weakened by degradation diminishes CO_2 absorption, indicating the importance of strengthening the range of responses which seek to reduce emissions from these sources. As explored in **Section 8**, specific priorities to safeguard sequestration include measures to ensure that protected areas are in fact fully protected, and the need for rigorous assessment of degraded forests within restoration programmes, so as to avoid conversions where there is significant recovery potential.

There are some indications that this priority is beginning to be recognised within the policy arena, as seen in the recent New Climate Economy (NCE) report and other contributions.[76] The NCE, for example, estimates the annual sequestration potential of forest recovery and reforestation as up to 4GtC,[77] while a recent policy brief estimates the combined potential of curbing emissions plus safeguarding and increasing sequestration in a range of 24-33% of all mitigation.[78,79]

The tropical forest carbon accounting challenge

Achieving certainty on the total annual volume of carbon emissions released as a result of tropical deforestation and degradation remains an elusive goal. Emissions released as a result of changes in a living ecosystem – changes triggered by the burning and decomposition of trees and other vegetation, and disturbances to soils – are much more difficult to quantify than those arising from burning fossil fuels.[80] And unlike fossil fuels, forest systems also act as sinks, removing CO_2 from the atmosphere and sequestering them via photosynthesis.

A major factor contributing to uncertainty[81,82] is the difficulty of achieving precise quantification of the exchanges (fluxes) of greenhouse gases that occur in the three-way traffic between tropical forests, the atmosphere and the seas (biogeochemical cycles).[83,84,85] These challenges are compounded by the fact that a proportion of these exchanges is a part of natural biosphere functioning, meaning that some emissions and some sequestration occur without direct human agency.[86] Other factors contributing to the difficulties include; sources of emissions that are not fully accounted for;[87] changes in the composition of overall emissions;[88] and the conventions of *gross* and *net* accounting.

Peatlands, mangroves and other exclusions

Of these issues, the exclusion of some sources from greenhouse gas accounting perhaps has the greatest influence on the perception of the magnitude of tropical forest emissions. Data on CO_2 releases from peatlands, mangroves, shifting cultivation, wood harvest and forest degradation are included in some studies but not in others, with estimates of peatland emissions entirely absent from models which simulate changes in plant biomass and carbon fluxes.[89] It is worth noting, for example, that peatland emissions are not included in the Harris *et al* and Houghton data given in **Table 3**.

One school of thought on emissions from tropical peatlands is that they should not be included in standard estimates because of year to year variability (a function of the incidence of drought and fires – events that are often triggered by conversion to agriculture and biofuels). However, this results in a zero for the source in some calculations. Rather than excluding the data, a sensible response would seem to be to include multi-year averaged emissions.

Gross *vs.* net accounting

The concept of *net* accounting for land-use fluxes (*gross* emissions minus sequestration, or the balance of source *vs.* sink) was developed in recognition of the dual function and the difficulties of separating out anthropogenic from natural contributions, on both sides of the ledger. Net accounting remains the default approach.

Whilst the rationale behind the adoption of net accounting is understandable, it has the potential to distort perceptions of both emissions and sequestration. For example, the 2013-2014 IPCC report (AR5) estimates that c.3GtC is released annually as emissions from global land-use change.[90] This is 25% of all anthropogenic carbon emissions (using data from Le Quere *et al*, see **Table 3**). However, these emissions are 'offset' in AR5 by c.2GtC of sequestration. This latter figure includes CO_2 absorption by agricultural lands, which are assumed in the analysis to be neither a net carbon source nor a net carbon sink in annualised terms – sequestration equals emissions.[91] The overall net difference (0.9GtC – 1GtC) is largely attributed to emissions from tropical forests, thus leading to the widely cited 10% figure (for or 2002-2011, on a 'net average' basis).[92] Given these complexities, it is easy to see how different representations of CO_2 emissions data can contribute to confusion in the understanding of the role of tropical forests and other land-uses in the climate context.

Other GHG emissions from land-use

An additional factor that can distort perceptions relates to the need for precision in the differentiation between greenhouse gases. For example, the IPCC's 2001 Third Assessment Report (TAR) saw land-use activities as responsible for approximately 25% of total anthropogenic carbon emissions, (with deforestation in the humid tropics identified as the principal component);[93] seemingly little different in proportional terms from the 24% estimate of 'anthropogenic GHG emissions' in AR5.[94] But the comparison is inexact: the AR5 figure includes other greenhouse gases (e.g. methane, nitrous oxide) as well as carbon dioxide.[95]

Changes in the composition of anthropogenic carbon emissions

Carbon emissions from fossil fuels have risen sharply since 2001, from 6.9GtC in that year to 9.1GtC in 2010.[96] The upward trend continues, with Le Quere *et al* estimating 9.7GtC for 2012.[97] Set in this context, the danger of focusing solely on the deforestation component of tropical forest emissions is apparent. If the Grace *et al* data (see **Table 3**), are applied to the Le Quere *et al* estimate, then deforestation accounts for 7.69% of all carbon emissions in 2012, a figure that could encourage the perception that tropical forest emissions are reducing.

Anthropogenic versus non-anthropogenic carbon emissions and sequestration

As explored above, the extent to which current sequestration can be seen as 'non-anthropogenic' is debatable, for example in the case of the human actions taken to reforest, or to place large tracts of tropical forest in protected areas (amongst other protective measures), where they continue to grow and remove CO_2. Conversely, it is the case that while some of the 'gross'[98] emissions from tropical deforestation occur naturally (e.g. via hurricanes, landslides, natural decomposition, and fires which follow periods of drought), most are attributable to man.

One response might be to argue that disentangling anthropogenic from non-anthropogenic causation is so inherently difficult[99] that the net accounting approach is the best available compromise. Whilst understandable, over-simplification via net accounting has tended to lead to under-recognition of the scale and significance of emissions from degradation, and the vital mitigation provided by sequestration.

Overall mitigation priorities

Another response is to stand back from the continuing uncertainties and wide data ranges and attempt to distil the key lessons from the complexities. These can perhaps be summarised as:

- Deforestation and degradation, in aggregate, account for as much as 21% of all anthropogenic carbon emissions, a higher than often recognised share of the overall total;
- Sequestration has largely been seen as a free service provided by nature; there have long been flaws in such a characterisation, but more importantly, the level of service provision is likely to be seriously reduced if the CO_2 absorption capacity of tropical forests continues to be eroded by deforestation and degradation;
- If efforts are redoubled to reduce carbon emissions from deforestation and degradation, and to safeguard existing tropical forest sequestration, the combined effect could be as much as 24-33% of all carbon mitigation;
- Curbing emissions from deforestation should continue to be the leading priority, reflecting the near irreversibility (at scale) of complete forest loss, and the high CO_2 releases per hectare;
- Emissions from degradation are greater than generally recognised (probably at least as great as those from deforestation) and accelerating; commensurate policy responses are a pressing priority;
- Success in reducing emissions from deforestation and degradation is likely to generate a second order mitigation gain, because more protection and fewer disturbances will catalyse more sequestration.

Photo: Chris Perrett, Naturesart

3 Tropical forest ecosystem services

Summary points

- New science since 2000 has enriched our understanding of how tropical forests (including peat and mangrove forests) maintain and renew themselves through an array of ecological and environmental interactions;
- The findings highlight how logging, defaunation and other disturbances disrupt or extinguish these processes, leading to weakened forest resilience;
- Loss of resilience impairs ecosystem functioning, particularly the carbon and water cycles;
- These cycles drive the services on which humanity is dependent – including rainfall generation, regulation of water supply, CO_2 absorption, and carbon storage;
- Forest protection and logging polices appear to lag behind the science: there is a strong case for the rapid incorporation of current ecological understanding into policy and practice.

Introduction

Tropical forests provide a wealth of ecosystem services that are of critical importance to humanity:

- Storage of a quarter of a trillion tons of carbon in above and below ground biomass, equivalent to one third of the carbon stored in economically recoverable oil, gas and coal reserves;[100,101]
- Reduction of CO_2 concentrations in the atmosphere via sequestration, with potential to further increase carbon storage in intact, degraded and secondary forests;

- Regulation of local, regional and global water and climate services within tropical forests and beyond (including in agricultural areas), through interconnected functions, including: water storage and transportation; cloud formation and rainfall generation; and the cooling effect of evapotranspiration;
- Maintenance of a rich array of flora and fauna which interact ecologically and environmentally to ensure forest renewal and resilience – and provide an irreplaceable storehouse of genetic material from which useful products can potentially be derived;
- Soil formation and protection, including regulation of sediment outflows; and
- Provision of shelter and livelihoods for indigenous communities.

These are indispensable services for human wellbeing; yet because of difficulties in their quantification and their near absence from markets, they are often taken for granted. However, recent findings from tropical science have significantly advanced knowledge, in ways that may presage greater recognition of their value.

Findings from recent tropical forest ecosystem science

Many of the advances in tropical forest ecosystem science point to the feedback loops between forest ecology, biodiversity and carbon storage; for example the weakening of forest resilience and renewal capacity resulting from defaunation (the local or regional extirpation of seed-dispersing mammals and birds), which ultimately leads to reductions in forest carbon stocks.

Further scientific findings are enriching our understanding of the impacts of tropical deforestation and degradation on a range of other ecosystem services. These include disruption of local and regional climate regulation, including altered rainfall generation (see **forests and water**, below); threats to the retention, purification and provisioning of freshwater and transportation of water-borne nutrients; weakening of the capacity of forests to control sediment outflows; and the loss of storehouses of genetic resources with the potential to provide benefits via pharmacology and domestication of food plants.

New science is also adding valuable insights in the adaptation context. Recent findings indicate that the physical effects of global warming (including increased incidence of high air temperatures and extreme weather events) are likely to be especially acute in tropical regions,[102,103] with consequent serious impacts on human health and livelihoods. Forests and other tree cover will be become even more vital as sources of rainfall and freshwater, and for their cooling function.

At the same time, climate change may weaken the resilience of tropical forests (especially when combined with deforestation and degradation), leading to negative impacts on carbon storage, emissions, and water services.[104] Wise management, including through the retention of large areas of intact forest, will be a key mitigation and adaptation step – increasing the chances that forests will be able to continue to provide vital ecosystem services, with circularity to the argument, as such services will become ever more critical as the impacts of climate change intensify.

Mutually reinforcing: tropical forest carbon, ecology, and biodiversity

There are many studies which emphasize the importance of tropical forests for biodiversity, and the inter-connectedness and dependency between species and forest systems.[105] These provide insights on maintenance of the overall ecological integrity of a forest, for example the way in which disruption and degradation occur ('trophic cascades')[106] when populations of keystone species (e.g. large carnivorous[107] and herbivorous mammals) are reduced or become locally extinct (extirpation), or when invasive species are introduced.[108]

The same degradation factors that trigger tropical forest emissions also cause biodiversity losses and the weakening of ecological interactions. Several leading figures within conservation biology have highlighted the possibility that the aggregate effects are lowering the resilience of forests and other tropical ecosystems[109] to such an extent that 'tipping points' are being approached, when 'state-shifts'[110] may occur – the breakdown of ecosystem functioning. Others have extrapolated the forces at play to depict the consequences at the planetary level: the concept of boundaries or limits, beyond which humanity will no longer have a 'safe operating space.'[111,112]

Much of the research in this area is comparatively recent, with most having been published since 2000.[113] It is perhaps therefore unsurprising that the findings are yet to fully inform policy and the practical approaches taken for tropical forest protection and restoration.

The unpaid agents of tropical forest carbon sequestration and storage

In temperate countries, the pollination and seed dispersal processes that enable natural forests to renew themselves are principally carried out by wind and water. By contrast, studies suggest that in tropical forests, 80 per cent of pollination is carried out by insects, birds, bats, and monkeys that interact directly with pollen producing flowers on trees,[114] while fruit-eating birds and a wide array of mammals account for as much as 85 per cent of woody rainforest species dispersal.[115] In general, the bigger the seed, the bigger the animal that disperses it, and the bigger the tree.[116] Research also points to higher carbon storage resulting from high tree species diversity.[117] Defaunation (principally caused by hunting and the bushmeat trade) thus has a large potential impact on forest regeneration.

The importance of large trees as carbon sinks

Large 'old' trees are keystone components of forest ecosystems, providing nesting and sheltering cavities, creating distinct microenvironments, playing crucial roles in hydrological regimes and providing food for myriad animal species. They also play a greater role in carbon storage than is sometimes assumed: one study found that, on average, large trees account for 25-45% of above-ground biomass, despite only constituting 1-4% of trees larger than 10cm in diameter.[118]

Recent science[119,120] has also challenged the (widely cited) view that mature forests become senescent and thus release as much (or more) CO_2 from decomposition, evaporation, transpiration and oxidation as they absorb via photosynthesis. The opposite may well be the case: one study found that a single big tree can add the same amount of carbon to a forest within a year as is contained in an entire mid-sized tree.[121] Given the very high carbon storage values (more than 400 tons of carbon per hectare)[122,123] reported for some tropical forests, and the slow growth rates[124] and multi-century lifespans of many large trees,[125] there are strong climate mitigation reasons to protect large trees across the tropics. The implications for selective logging, as currently practised, could be profound.

Other biodiversity-mitigation synergies

In addition to the presence of pollination and dispersal agents, and big trees, the continuing ability of tropical forests to store and sequester carbon rests on a complex interaction of factors. A range of studies inform the broader perspective: many animals are involved, across all the food chains;[126,127] soil fungi,[128] pathogens and other microbial life[129] play key roles in soil carbon storage, and are threatened when deforestation occurs.[130] Some initial mapping shows that higher biodiversity is generally congruent with higher carbon storage.[131] This relationship is unsurprising, and is also known to apply in other terrestrial contexts, such as mixed-species plantations and some forms of agroforestry,[132] though involving lower levels of both biodiversity and carbon.

Ecosystem dynamics in recovering secondary tropical forests

Recent studies give cause for optimism on the potential for secondary[133] tropical forests to regenerate, if adequately protected. One study found that near-maturity was reached (in biomass terms) after 80 years, with tree species richness recovering within c.50 years, although full recovery of tree species and forest composition, and biodiversity, is likely to take much longer.[134] Other research has focused on the role of nitrogen, a key ingredient in re-growth rates, with N_2 fixing tree species in Panama, for example, having been found to accumulate carbon at much faster rates than others.[135,136] However, some recent studies suggest the need for caution in the extrapolation of such findings.[137]

Tropical peatland, mangrove and montane forests

While lowland tropical forests growing on mineral soils are the most abundant, recent science has enhanced understanding of the significance of other tropical forest types. For example, findings on montane forests indicate that their carbon stores are much greater than previously estimated;[138] and recent research on mangroves has established that, although small in area in relative terms, they are very rich in carbon, largely stored below the surface (as in peatland systems).[139]

The importance of tropical peatland forests as carbon sinks has long been known, and the burgeoning knowledge from science in this area consistently underlines the huge amounts of carbon they retain, and conversely, the high level of emissions resulting when they are burned and drained.[140] A recent study reporting that annual emissions of 0.5GtC[141] (or more) are arising from their loss and degradation is especially noteworthy A further point of note is the significance of peat forest carbon stores in both Amazonia and south-east Asia.[142] To date, these findings do not appear to have achieved significant impact within global forest policy.

Adaptation capacity of tropical forests

There are a range of studies which report increasing carbon storage in tropical forests, with the presumption that the already observed increase in global warming is stimulating more CO_2 absorption. These include research which finds that: CO_2 absorption globally has been under-estimated by 16% in the 1901-2010 period;[143] atmospheric CO_2 concentrations would be 85ppm higher without the enhanced vegetation growth that has occurred;[144] and that there are observed increases in the diameter of tropical trees in Africa that are above previously reported growth rates.[145] However, the attribution to fertilisation is not supported by all studies. One recent paper found an increase in water-use efficiency but no growth stimulation from fertilisation.[146]

These issues have broader adaptation implications beyond the temperature-CO_2 relationship. For example, one study found that changes to the pattern of seasonal rainfall can be more critical for resilience than the annual volume of precipitation,[147] while another concludes that tropical and other land sinks may be exhibiting greater sensitivity to increases in air temperature,[148] a threat that is exacerbated by deforestation and other land-clearance.[149]

There is a danger that these findings could encourage either complacency (as enhanced tree and plant growth are removing more atmospheric pollutants, the need to reduce emissions is less urgent) or disengagement (forests will dry out and die as temperatures soar, regardless of conservation action). However, the available knowledge supports neither position, and the arguments for pursuing the effective protection and restoration of forests at the greatest scale possible remain as strong as ever.

Amongst the many factors at play is uncertainty over 'the airborne fraction' (the proportion of released CO_2 which remains in the atmosphere – currently 40%). While one recent study finds that this is not changing significantly,[150] another articulates the fear that terrestrial and ocean[151] systems may reach a CO_2 absorption limit.[152]

Forests (and trees in agricultural lands and in settlements) also provide a range of other services that support the ability of people and landscapes to adapt, survive and prosper as climate impacts mount. These include: soil erosion prevention, watershed maintenance, agro-ecological resilience, and coastal buffering (where mangrove forests are protected or re-grown).

Tropical forests and the water cycle

While the roles of tropical forests in water storage and rainfall generation have long been known, recent research is expanding our understanding of the effects of deforestation and degradation on regional and global climates.

Tree cover, vegetation and soils in tropical forests store huge volumes of water,[153] and also move them from the soil into the air via transpiration, cooling the atmosphere and driving cloud formation and precipitation. Deforestation disrupts this cycle, reducing storage and transpiration. The impacts include increases in temperature, changes in the amount (usually a reduction) and distribution of precipitation,[154] and loss of soil moisture, contributing to droughts in some areas and flooding in others.[155,156,157]

One study of the vegetation canopy of the Amazon found that precipitation has declined by 69% across much of the Basin since 2000, triggering a 'diminished vegetation greenness' which threatens forest resilience, and thus the capacity for carbon uptake and climate regulation.[158] Recent events in Sao Paolo, where 20 million people are at water risk (see **Section 4, Valuation challenges**), are perhaps an indication of the potential consequences.

Scientists warn of potential tipping points, given that these impacts could trigger positive feedback loops, with reduced water availability driving die-off, in turn increasing emissions and further accelerating climate change.[159] Due to varying geographies, the Amazon and Central Africa are more susceptible to deforestation-driven warming and drying than South-east Asia.[160] Such studies are the most recent additions to a growing body of research that suggests that deforestation, leading to changing weather patterns and reduced water availability, poses major risks to the agricultural output of both tropical forest countries and surrounding regions.

Integrating ecology within policy

The growing body of evidence on the inter-connectedness of tropical forest carbon sequestration and storage, hydrology, ecology, and biodiversity highlights the need for a more integrated approach, both within the science and policy communities, and between the two. Without a concerted effort, the likelihood is that the sum of knowledge will remain less than the parts, and that policy will continue to lag well behind the science. For example, though the science that signposts defaunation as a major driver of forest degradation (and consequent carbon loss) is of high relevance to biodiversity, climate change and economic policy, it does not yet seem to be widely recognised or factored into policy formulation. Similarly, the role now understood to be played by large trees has had little discernible effect on logging policies.

More broadly, the science highlights the fundamental importance of ecological interactions – and of the diversity of animal and plant species on which they rest – for tropical forest renewal and resilience. This is as true for recovering forests as it is for those in a mature state. And though there may be uncertainty as to the point at which rising temperatures and extreme weather events will threaten whole tropical forest ecosystems, the case for taking all practical possible measures to protect and restore forests is abundantly clear. The maintenance of carbon and water functions is critical for human wellbeing, including for the food security of tropical countries and agricultural production in regions adjacent to forests.

Piles of slash are burned to clear the rainforest land for agricultural production near Onane, Democratic Republic of the Congo, May, 2009. Photo ©Daniel Beltrá via Catherine Edelman Gallery, Chicago

4 Drivers of forest loss and damage

Summary points

- The drivers of deforestation and degradation vary across the tropics and include commercial and smallholder agriculture, mining, roads and infrastructure, legal and illegal logging, and defaunation;
- They are also inter-connected and dynamic, implying that they need to be addressed holistically, including on a regional and local basis;
- These challenges are compounded by difficulties relating to their valuation, and a range of definitional issues;
- Projected increases in global demand for wood products and agricultural commodities will significantly increase pressure on tropical forests over the next few decades.

The forces that cause tropical deforestation and forest degradation vary greatly through time and space, and as a function of socio-economic and political factors. Across an extensive economics and policy literature, there is consensus that the main direct drivers include: global commodity supply chains (principally palm oil, beef, soy, pulp and paper, maize, rice, and sugar cane), driven in turn by global increases in population and consumption, and changing diets; oil and gas extraction and mining; the development of roads and other infrastructure; smallholder agriculture; fuel wood collection and charcoal production; forest fires which are often a precursor to conversion; and legal and illegal logging. All are considered briefly below, as is the role of the under-valuation of tropical forests as a 'meta-driver'.

Schematics and models of the drivers tend to treat each of them as discrete, but evidence from on the ground analyses indicates that they are inter-connected and dynamic: forest degradation often paves the way for deforestation, but not necessarily in a linear fashion. In addition, the triggers and pathways leading to forest damage and loss are multiple and hard to predict, and are themselves driven by underlying causes (sometimes referred to as indirect drivers), including population growth, lack of secure land tenure, poverty, migration, land speculation, market trends, and weak governance and regulation.

Two further factors are also explored here: the often overlooked part played by defaunation as a driver of forest degradation; and the challenges raised by on-going confusion over the definition of deforestation, the absence of a clear definition for degradation, and lack of clarity on the distinction between natural and planted forests.

Valuation challenges

Under-valuation of tropical forests can be considered a meta-driver of deforestation and degradation. Despite increasing knowledge and the growing desire and will of international agencies and national governments to achieve forest protection, the true economic contribution of forests to the wellbeing and prosperity of tropical nations and global society is not yet factored into the policy frameworks that govern land use and wider economic decision making.

At the same time, there is some evidence that higher valuation is beginning to play a part in policy. The recent successes achieved reducing the rate of forest loss (Brazil) and preventing it from rising (Guyana), Norway's agreements with Liberia and Peru on REDD+, the zero-net deforestation commitments made by a number of global companies (on the supply as well as the demand side see **Section 9**) all imply valuations for standing forests that are greater than the alternative land-uses. Large-scale multilateral commitments at a jurisdictional scale, including through the Forest Carbon Partnership Facility (FCPF) and the BioCarbon Fund Initiative for Sustainable Forest Landscapes (ISFL), also seem to be garnering political attention in REDD+ countries.

Agricultural opportunity costs and forest protection

The difficulties of achieving full valuation for the carbon, water and other ecosystem services provided by tropical forests are seen at their starkest when viewed through the lens of agricultural opportunity costs – the revenues that would be required from forest protection in order for it to out-compete other land use options in conventional economic terms. On this basis, a ton of CO_2e, (the most widely used proxy for the value of standing tropical forests) would need a price of US$25–40 to outbid timber revenues;[161] and over US$100 to out-price palm oil.[162] With the average price for forest carbon credits in the voluntary market at c.US$7–8,[163] there will clearly need to be a very large change in the valuation of and price paid for carbon, or other forests services, before standing forests can withstand unconstrained market forces.

Some may maintain that simply rehearsing the 'forests vs. agricultural opportunity costs' argument is tantamount to an endorsement of this approach; the perpetuation of a false dichotomy. However, the arguments are included here as this approach, despite its drawbacks, continues to underpin decisions leading to deforestation and degradation in a number of tropical countries (as it does in other environmental contexts elsewhere).

A number of factors suggest that there is a way out of this impasse. Not all forestlands are suitable for conversion at large scale: they may be too remote and inaccessible (e.g. tropical montane forests, lack of rail or road infrastructure, lack of available labour), of poor soil quality, or unattractive for a host of other reasons, including conversion costs. Some efforts to protect forests seek to leverage such conditions, concentrating on areas where the marginal value of conversion narrows, relative to protection.

It is also the case that in many instances there are viable alternatives for agricultural producers which do not involve deforestation, because of the availability of already deforested lands with low carbon and ecological values (see supply chains, **Section 8**). While switching production to alternative lands may incur marginal additional economic costs, these are likely to be lower than in the forest conversion context.[164] In aggregate, the implication is that past perspectives on agricultural opportunity costs are in need of re-examination.

A further component of the debate over agricultural (and other) opportunity costs relates to the tendency to conflate analysis of opportunity costs with policy formulation. It appears that frequently the decisions to convert or not to convert forests rest upon the opportunity costs with reference to alternative agricultural or other commodity use. Given the low price of carbon and the high value of other commodities, such an equation is rarely going to come out in the forests' favour. The absence of a proper valuation of the other services (both ecological and social) that forests provide, means that forest policy is usually decided on the basis of a very narrow and not very representative metric (see below).

Climate mitigation opportunity costs and forest protection

The opportunity cost approach is also applied to climate mitigation. The consensus view is that achieving emissions reductions from tropical forests is less expensive than other interventions, with one review of twenty-nine studies reporting an average cost of \$2.51/tonne CO_2 (tCO_2) for tropical forest mitigation, with only one above \$10.[165] By contrast, the costs of wind and solar abatement are perhaps four to ten times higher.[166]

The data are rightly seen as strong supporting evidence for one of the central tenets of REDD+: the contention that tropical forest protection is economically feasible and attractive as a climate mitigation intervention. But, just as assumptions on agricultural opportunity costs can be erroneous in particular circumstances, there are dangers in treating low-cost tropical forest management as a given.

For example, one meta-analysis found that many estimates of REDD+ mitigation costs are too low because they do not adequately allow for policy realities and practical implementation issues;[167] while another study suggests that REDD+ success requires an understanding of all the incentives that drive forest loss, so that domestic policy can be tailored to specific settings.[168] Human population density is also seen as a key cost variable.[169] These factors point to the likelihood that the costs of actions to address the drivers of deforestation and degradation are likely to be as variable as the drivers themselves.

Legal systems and political will

Brazil's success in reducing forest loss shows that it is possible to sharply reduce deforestation if there is sufficient political will, and when legal systems are robust and effective - and if actions are supported by large domestic and multinational companies. Relatively low public sector expenditures were channelled into forest management and law enforcement, underpinned by strong state and federal laws.[170] While this approach applied significant regulatory costs to companies and smallholders, it also conferred benefits, where actors were in compliance. The alternative route – compensation payments reflecting the opportunity costs of foregone soybean expansion – would have been far more expensive. The lesson may be that broader social and political factors should be included in decision-making, alongside valuation assessments and appraisal of implementation options.

Water and other local ecosystem services as rationales for forest retention

Local ecosystem services provide a further valuation perspective; in certain circumstances their functional importance clearly overrides other economic considerations. Some of the best examples relate to water: notably the measures taken to protect forested mountains in Kenya because of their critical role in the provision of water supply to Nairobi and other population centres,[171] and similar approaches for watershed forests serving Jakarta, Dar es Salaam, and other cities.[172] Such approaches are likely to be replicated elsewhere in the tropics as the linkages between deforestation and hydrology become better understood, and as evidence mounts of the devastating consequences that can result from forest loss: Sao Paolo, where 20 million people are at water risk[173,174] perhaps offers a salutary lesson.

A major new study on the forests-water relationship reinforces concern: tower, ground-based and satellite observations indicate that tropical deforestation results in warmer, drier conditions at the local scale, and that future agricultural productivity in the tropics is at risk from a deforestation-induced increase in mean temperature and associated heat extremes, and from a decline in mean rainfall or rainfall frequency.[175] Other forest services that have attracted attention in valuation terms include tourism, biodiversity and the provision of non-timber forest products.[176]

These examples point to 'implicit valuation' as a factor determining the fate of forests, with water and climatic regulation often acting as the catalyst for protection. However, they need to be interpreted with caution; water supply rather than climatic conditions may be the catalyst in one context, or vice versa – or a combination of both. The variables imply that work on valuation could achieve more if the focus of attention shifted to the regional and local (especially where ecosystem benefits are evident) rather than the 'macro' and conceptual analysis which have tended to dominate thinking thus far.

Looking ahead, there is a powerful case for research that makes valuation of these regional and local ecosystem services explicit rather than implicit. This would help to foster wider recognition of ecosystem benefits (especially within the political and economic spheres), and narrow the perceived gap between agricultural opportunity and forest protection costs.

Natural capital as a valuation tool

The concept of natural capital valuation has gained momentum, building on a model for the contribution of earth's ecosystems to the global economy that was first developed in the 1990s.[177] Some studies look at natural capital in the climate change context,[178] while others focus on water,[179] restoration,[180] natural capital value to developing economies,[181] REDD+,[182] and the mapping of natural capital assets.[183] Several initiatives are seeking to facilitate the incorporation of natural capital concepts within mainstream economic policy. These include The Prince's Accounting for Sustainability Project (A4S), the Natural Capital Forum, the Food Climate Research Network, the Natural Capital Coalition, and the Waves Partnership.[184]

The perspective from tropical countries, and potential implications of recent agreements

One recent study supports the notion that domestic public support for forest protection in tropical countries increases as prosperity rises.[185] But the study also indicates that government action lags behind such attitudinal shifts. In turn, those governments might argue that donor countries have not yet provided funding at a scale sufficient to help bridge the gap between the revenues that are available from carbon credit and ecosystem services payments, and those that can be derived from alternative land-uses.

That is the debate in the abstract. However, when specific funding agreements are scrutinised, there seem to be indications that the 'implicit valuation' of local and regional benefits from retaining forests may be tipping the balance in favour of further forest protection. The recent agreement between Norway and Liberia is perhaps instructive in this regard.[186] It is framed around a wider set of assumptions than simply the value of avoided forest carbon emissions; and it aligns with other donor and private sector initiatives which seek to help Liberia meet its goal of developing sustainably, along a low-carbon pathway.

Perhaps the key lesson from this example is that the option to trade forests for higher short term returns from alternative land-uses (such as palm oil) was set aside within the agreement in favour of forest protection, underscoring the point that Liberia – and many other countries - will need strong donor support (political and economic as well as financial and technical) if they are to increase forest protection at scale.

Definitional challenges

A cross-cutting issue that acts as an indirect driver of forest loss and damage is the problem of definition. There are three principal elements which create difficulty: the absence of a clear distinction (especially within the FAO data which underpins forest policy) between natural forests that have grown (and renew) themselves and those which are planted (plantation forests, planted forests); the definition of standing forest as having a minimum of 10% canopy cover;[187] and the absence of an agreed definition for forest degradation.[188]

The first creates uncertainty over estimates of the extent of forest cover, and the actual natural forest decrease or increase occurring.[189] The second, the definition of deforestation as less than 10% canopy cover, might be characterised as closing the stable door after the horse has bolted; information on the *probability* of deforestation is absent, meaning that many forests currently counted as standing are in fact severely degraded and on the verge of disappearing. The third factor compounds the problem: if, for example, a definition of 'severe degradation' existed, this would assist efforts to rescue forests from the brink. Degradation is also problematic in terms of its scope, with studies choosing to lump peatland emissions in the category or to exclude them from consideration altogether. A further inconsistency is the effective exclusion of emissions released through loss of mangrove forests from all mainstream calculations.

These definitional issues may seem arcane and theoretical. But their impacts on policy and action can be significant. At the minimum they can foster disagreements (as in a recent set of exchanges[190] over the extent of deforestation and forest degradation in Indonesia) that may impede progress. And looking forward, there is potential for definitional issues to constrain the effectiveness of two very positive developments.

The first relates to the commitments made on the supply and demand side by commodity companies involved in sourcing agricultural commodities from South-East Asia, South America and Sub-Saharan Africa. Several are employing the *'zero-net deforestation'* concept, which theoretically allows for a natural forest to be cut down so long as an equivalent area of planted forest is established – with, *inter alia*, major carbon and biodiversity implications. The second is that the ambitious forest landscape restoration pledges made at the UN Climate Summit will inevitably need to address the challenge of degraded forests and the emissions and sequestration losses that will occur if they are converted to agricultural use (see **Section 8**).

Agricultural commodities as drivers

A benchmark 2012 study by Hosonuma and others estimates that commercial agriculture has over recent decades accounted for approximately 40% of all tropical deforestation (excluding degradation, which is treated as a separate category), although the proportions vary by continent (66-68% in Latin America; 33-35% each in Africa and Asia).[191,192] When the impacts of smallholder/subsistence farming are included, the overall contribution of agriculture to deforestation has remained constant since the 1980s, at 80%. However, the study notes that the share of deforestation attributable to commercial agriculture within the total for the sector is likely to be increasing:

'For decades the common view was that growing populations of shifting cultivators and smallholders were the main driver of forest changes. More recently, it has been argued that commercial actors play an increasingly larger role in the expansion of agriculture into the forest... This seems at least to be valid for the Amazon region and Southeast Asia. Here agribusinesses, producing for international markets (cattle ranching, soybean farming and oil palm plantations), were identified as main drivers of post-1990 deforestation… Looking at the development of deforestation drivers through time the contribution of commercial agriculture increases.'

Hosonuma, N., *et al.* 2012. *An assessment of deforestation and forest degradation drivers in developing countries.* Environmental Research Letters, Vol 7.

A number of recent reports[193] support this view, with one estimating that commercial agriculture drove 71% of all tropical deforestation in the 2000-2012 period.[194] Much of the deforestation is seen as being driven by export demand via supply chains (see **Section 8**). These new findings need to be interpreted with some caution; more peer-reviewed research is needed to confirm the overall data, particularly the updating of trends in deforestation attributable to smallholder and subsistence agriculture.

Nevertheless, the commercial agriculture component is clearly increasing. At the global level, the commercial crops most heavily associated with deforestation are soybean, maize, oil palm, rice and sugar cane,[195] while more than half the total is associated with pasture and feed for cattle. Data on the split between the domestic and export components is hard to ascertain with absolute precision, in part because trends vary year on year as a function of many factors, including macro-economic conditions.

But there seems little doubt that the export share is rising. One new study found that c.33% of deforestation (from beef, soy, palm oil and wood products) in eight countries (Argentina, Bolivia, Brazil, Paraguay, Democratic Republic of the Congo, Indonesia, Malaysia, and Papua New Guinea) was embodied in exports, mainly to the EU and China, with the export-share increasing for every country since 1990, except Bolivia and Malaysia.[196]

The international trade seems to be primarily crop-based, with another report noting that while 33% of crops are exported, the figure for livestock products is much lower, at 8%.[197] But from the emissions perspective this can be misleading, as these are higher (per unit of output) for beef, eggs and dairy than for crops.[198] The EU is seen as the largest global net importer (principally soy from Brazil, Argentina and Paraguay, meat products (including leather) from Brazil,[199] palm oil from Indonesia and Malaysia, cocoa from Ghana and Nigeria, and nuts from Brazil).[200] China is also a significant importer, particularly for soybean.[201]

Tebaran Agut. Photo © Mattias Klum

Looking ahead, one report argues that where source countries have developed economically viable infrastructure and capacity to export agricultural commodities, the bulk of subsequent production is consumed outside of the country of origin.[202] This finding broadly calibrates with another study that suggests that commercial agricultural expansion in the tropics is mainly being driven by export demand.[203] However, as noted earlier, these findings need to be interpreted with caution. Domestic demand in many countries is also likely to place increasing pressure on forests, as a function of rising prosperity and population growth.

Putting the domestic or international destination of commodities aside, a more generic challenge can be seen. This is that as yield gaps (both expected production relative to demand, and average versus potential production) are projected to increase between now and 2050,[204] pressures on tropical forests from commercial agriculture seem likely to intensify.

The guidance informing responses to this challenge is varied, indicating that there is no single solution. Avoiding the highest emitting conversion is seen as a key priority, with much attention currently focused on moving palm oil production from peatland forest to already deforested lands, and avoiding expansion into forests of high carbon stocks and conservation value.[205]

Beyond this, one common response is embodied in the *sustainable agricultural intensification* approach,[206] which seeks to increase yields from existing lands. One study concludes that intensification in Brazil could obviate the need for further deforestation;[207] and an ISU report presents similar findings for Ghana and Central Kalimantan, Indonesia, as well as for Brazil.[208,209] But intensification could also trigger unintended negative consequences: one study explores the likely impact of higher yielding next-generation 'super palms', concluding that increased revenues per hectare may drive further deforestation in Indonesia and Malaysia, and drive soybean production from temperate to tropical countries.[210]

Others are focusing on *climate-smart agriculture*[211] as a model that takes account of responses to global warming as well as impacts on tropical ecosystems.[212] One part of this response would be to better align crop choice on existing agricultural lands with expected conditions.[213] Another is to look at the link between production and human nutrition: one study suggests measuring people nourished per hectare, as well as tons of output.[214] The launch (by the newly formed Global Alliance for Climate Smart Agriculture) of the Climate Smart Agriculture Declaration at the UN Climate Summit in New York in 2014 indicates that there is considerable governmental, private sector and civil society support[215] for the approach.[216] However, concerns have also been raised by some NGOs, and others,[217] on the grounds of potential inequity (developing countries may be asked to shoulder some of the mitigation and adaptation burden for which high emitting developed nations are largely responsible), and a perceived lack of clarity on the meaning and scope of the term.

Smallholder agriculture, fuelwood and charcoal, and forest-dependent livelihoods

The Hosonuma study estimates that between 27–40% of tropical deforestation (forest clearance and conversion) results from local and subsistence tropical agriculture, in a range quite equally distributed across Latin America, Africa and Asia. The study also reports that fuelwood collection and charcoal production account for an estimated 31% of the separate forest degradation (loss of some trees within a forest) category, largely in Africa. Livestock grazing causes some 7% of degradation.[218]

There is a voluminous literature on these topics, much of it based on detailed assessments of local studies, with results varying as a function of the many different factors at play. One overview focuses on the extent to which poverty alleviation and forest conservation are and can be made convergent.[219] Several studies cite a range of examples of where forest communities are and are not acting as drivers of deforestation.[220]

Other research concludes that agriculture is the prime cause of household-driven forest clearing,[221] while emphasizing the high dependence on fuelwood and forest products within some communities.[222] The extent of reliance on forests (e.g. for non-timber forest products) has also been assessed, with conclusions pointing to ever-changing dynamics.[223]

The overall conclusions from research are perhaps twofold. The emissions ascribed to local and subsistence agriculture (including livestock grazing), and wood fuel collection and charcoal production are significant components of overall tropical forest emissions. Equally, the underlying activities are at present critical for the livelihoods of very many people.[224]

Identifying solutions to these drivers is challenging. They will need to include the provision of incentives and support to local communities to pursue agro-ecological approaches and increase smallholder yields and market access; support for forest-dependent communities as they transition to local, decentralized alternative sources of clean energy; and the rolling out of schemes to substitute the use of fuelwood in rural homes with clean stoves and heaters.[225]

Mining, oil and gas extraction, roads and other infrastructure and urban expansion

In aggregate, mining and other extraction (e.g. oil and gas), roads and other infrastructure and urban expansion cause 27% of tropical deforestation: drivers which seem less damaging when viewed singly (7%, 10% and 10%, respectively), but which tend to manifest themselves in combination.[226] Mining is particularly significant in Africa,[227] but its impacts are also seen elsewhere, as explored in one study of coal mining in Indonesia.[228] Illegal gold mining contributes significantly to forest destruction in Latin America.[229] Roads have a pervasively catalytic impact, often triggering both forest degradation and deforestation in line with the 'fish bone' effect.[230] One study suggests that a large-scale global road-building zoning plan could be developed, based on avoiding areas with high environmental values and strategic road improvements for areas where agricultural development could be promoted with relatively modest environmental costs.[231] Another neglected issue is the inter-connectedness of deforestation and degradation drivers. For example, one recent study suggests that mining is triggering reductions in the populations of great apes in Central Africa.[232]

Illegal logging

Illegal logging has long been known as a key factor in deforestation and degradation, with a range of studies reporting on its extent, causes and consequences, including in Brazil,[233] Indonesia,[234] the Republic of Congo,[235] Ghana,[236] the DRC,[237] Papua New Guinea,[238] Cameroon,[239] Peru,[240] Malaysia,[241] Mozambique,[242] the Mekong and other parts of South-East Asia.[243] There is also extensive recent research on demand side drivers.[244] The causes, as shown in many of the studies, can often be traced upstream in supply chains to consumers in wealthy countries, as is concluded in a recent Chatham House report.[245]

FLEGT and the US Lacey Act

In response, both the European Union and the US have made considerable investments of political, human and financial resources to address illegal logging and the associated trade. The EU's FLEGT (Forest Law Enforcement, Governance and Trade) programme[246] was launched via the FLEGT Action Plan in 2003, with a range of objectives, including measures to regulate the trade in timber, public procurement processes and assistance to tropical countries on reform of forest industry practices.

An important legislative outcome was the adoption of the EU Timber Regulation (EU TR)[247] in 2013, which set out actions to prevent the import of illegal timber products to the European Union, and to encourage demand for timber from responsible sources. Countries exporting timber to the EU have received support for compliance with the EU TR via FLEGT Voluntary Partnership Agreements (VPAs).[248] Six countries (Cameroon, Central African Republic, Ghana, Indonesia, Liberia, and Republic of Congo) have signed VPAs, with another nine in negotiation with the EU. A similar pathway has been followed in the US, through a 2008 amendment to the US Lacey Act that prohibits importation of illegally harvested timber.

The impacts of these initiatives are inherently hard to assess,[249] partly as a consequence of the multiplicity of timber sources and destinations, and other forest industry complexities, and because both the EU TR and the Lacey Act have come into force relatively recently. Nevertheless, they are clearly beneficial. One study (for the Lacey Act) notes that China and Vietnam have taken some steps to address illegal logging;[250] another (published before the adoption of the EU ETR) estimates that illegal logging has fallen during the last decade by 50 per cent in Cameroon, by between 50 and 75 per cent in the Brazilian Amazon, and by 75 per cent in Indonesia, while imports of illegally sourced wood to seven consumer and processing countries studied are down 30 per cent from their peak.[251]

However, the translation of these advances into tropical forest emissions reductions is less clear. The goals of both initiatives embrace the legalisation of logging, as opposed to timber extraction prevention; and although environmental protection is part of their intent, they primarily address issues of social and economic equity in the utilisation of natural resources.

The several meanings of illegality

Until recently, illegal logging was principally seen as an agent of degradation: but a new study by Forest Trends[252] argues that illegal deforestation is also a major driver of forest loss, concluding that of the 71% of all tropical deforestation between 2000 and 2012 caused by commercial agriculture, cited above, 49% was due to illegal conversion. Of this total, 24% was the direct result of illegal agro-conversion for export markets.[253]

These findings require some qualification, because of the elastic nature of the illegal logging term. Up to now, perhaps the primary definition of illegal logging has been employed to describe illegal practices related to the harvesting, processing and trade in wood. Thus, the law may have been broken at any point along the supply chain, for example: logging with an illegally acquired license or in protected areas; harvesting over allowed quotas; processing of logs without the necessary licenses; non-payment of taxes; or exporting products without paying export duties.[254]

However, some studies and widely-cited data embrace 'informal logging' within the illegality definition: extractions undertaken by inhabitants of tropical forest regions, often for their own use and survival, including for burning as fuelwood rather than for timber purposes.[255] On this basis, illegal/informal logging accounts for as much as 50-80% of roundwood production in a number of African countries.[256] This is clearly a quite different meaning and challenge from the primary definition above.

The Forest Trends study adds a third meaning, through the redefinition of the concept of illegality to embrace concession permits granted by governments that subsequently have been deemed to be unlawful. This may be valid, but the implication is that past illegal logging data will need to be rebased in order to establish the underlying trend over a longer time frame.

Legal logging

For logging as a whole (legal and illegal), the current mainstream assumption (based on Hosonuma's benchmark paper)[257] is that it accounts for c.52% of forest degradation (exclusive of the logging that occurs via deforestation). As a new overview notes, rates of timber extraction are accelerating, driven by seemingly insatiable demand for tropical timber (see **Box 1**). A range of other studies broadly confirm the high levels of damage and loss deriving from logging operations (see **Box 2**). It can also be argued that forest losses triggered by uncontrolled fires (which account for 9% of forest degradation) should be partially attributed to logging, because the pathway to conversion is widely observed to follow the logging-fires-conversion chain of events; if logging is prevented, fires are less likely.

Box 1: The pervasiveness of logging in the tropics

'Population growth and increased global affluence have led to a rising and almost insatiable demand for tropical timber… In 2006, member nations of the International Tropical Timber Organisation (ITTO) exported over 13 million m³ of tropical, non-coniferous logs worth $US 2.1 billion, making a substantial contribution to the economies of these nations. As a consequence, many of the world's remaining tropical forests have been through at least one cycle of logging, with only 19 of 106 (18%) tropical nations reporting more primary than regenerating forest (mostly comprised of logged forest)… between 2000 and 2005 logging had approximately 15 times the geographic footprint of forest clearance in humid tropical forests. Moreover, rates of timber extraction have recently accelerated. For example, in Brazilian Amazonia, the area of forest disturbed by fire and/or logging increased by 20% between 2000 and 2010, despite the fact that deforestation simultaneously decreased by 46%. Logging intensities have been particularly high across Southeast Asia, where forests are dominated by commercially valuable dipterocarp tree species that enable timber extraction rates more than ten times higher than in Africa or the Americas. Between 1990 and 2009 some 80% of Malaysian Borneo was affected by previously undocumented, high-intensity logging or clearing operations, with large areas being logged multiple times.'

Source: Malhi, Y., *et al.* 2014. *Tropical Forests in the Anthropocene.* Annual Review of Environment and Resources, Vol. 39, pp125-159.

Box 2: Results of logging in tropical forests

- **Increased carbon emissions.** Forest fragmentation has caused significant – and previously unreported – carbon losses over the last decade: 599 million tons from the Amazon, and 69 million tons from Brazil's Atlantic forest. Globally, tropical forest fragmentation is estimated to release 200 million tonnes of carbon per year;[258]
- **Reduced capacity for carbon storage.** Forests that experienced both selective logging and understory fires stored, on average, 40% less aboveground carbon than undisturbed forests [Amazon];[259]
- **Logging as a precursor to deforestation.** Analysis of a 203 million hectare area of the Brazilian Amazon found that 16 per cent of selectively logged areas were deforested within one year of logging, rising to 32 per cent after four years;[260]
- Of the 6.6 million hectares deforested in several Indonesian jurisdictions (Kalimantan, Sumatra, Papua, Sulawesi, and the Moluccas) between 2000 and 2010, 27% were found within logging concessions;[261]
- In a large-scale study of primary forest cover loss in Indonesia between 2000 and 2010, almost all clearing of primary forests occurred within degraded types, meaning logging preceded conversion processes;[262]
- **Disturbance of large tracts of forest.** The impact of deforestation in the state of Mato Grosso in the Brazilian Amazon has long been recognised, but it is noteworthy that selective logging was responsible for disturbing 31 per cent of a 3 million hectare study area over a 13 year period (1992-2004), greater than the fraction lost outright to deforestation (29 per cent);[263]
- **Acceleration of primary forest loss.** From 2000 to 2010 almost 2% of the Democratic Republic of Congo's intact primary forests were degraded, for which fragmentation and selective logging were the leading causes, a rate of change which is expected to double over the next decade;[264]
- **Severe and previously undocumented degradation.** Nearly 80% of the land surface of two Malaysian provinces (Sabah and Sarawak) was impacted by previously undocumented, high-impact logging or clearing operations from 1990 to 2009;[265]
- **Unsustainable cutting cycles.** 'Peak timber' may be on the horizon for the tropics, because the standard cutting cycle of 30–40 years is too brief to allow the wood volume to regenerate;[266]
- **Demand for luxury wood products.** Ipê, 'the new mahogany' is being over-exploited in the Brazilian Amazon in order to meet demand (often European and American) for high quality decking and flooring.[267]
- **Selective logging drives biodiversity loss across the tropics.** A synthesis of observations from 48 studies conducted in already logged forests across the tropics identified logging and logging intensity as the dominant driver of the loss of mammals, amphibians, butterflies, dung beetles, and ants.[268]

Defaunation

Defaunation denotes the loss of both species and populations of wild animals, as well as local declines in abundance, in some cases leading to local extinction (extirpation). A major overview of the global state of wild animal populations by WWF estimates that abundance has been reduced by 52% since 1970.[269]

The WWF report follows in the wake of a surge of research findings that have been published in peer-reviewed papers in the last few years (see **Box 3**). The implications for tropical forests are large and seemingly little recognised. The declines impair the ability of forests to renew themselves as the species lost or reduced in number include the 'unpaid agents' of forest carbon storage, the mammals and birds that play critical roles in tree pollination and seed dispersal (see **Section 3**). These findings indicate that defaunation should now be seen as a significant driver of forest degradation, underlining the need for a redoubling of existing efforts, and new and ambitious policies and actions to curb declines (see **Section 8**).

Box 3: Recent findings on defaunation

- **Global declines.** Populations of terrestrial vertebrates are declining by 25% on average, and of invertebrates monitored globally, 67% show 45% mean abundance decline. As 70% of all animal species live in tropical forests, these trends are potentially catastrophic;[270]
- **African elephants.** 18 tree species in a lowland rainforest in the DRC are elephant-dependent for seed dispersal and renewal and are likely to go locally extinct as a consequence of the elephants themselves being on the verge of extinction.[271] Across central Africa, the population of forest elephants is now less than 10% of its potential size and occupies less than 25% of its potential range;[272] and in Samburu, Kenya, 8% of the elephant population were illegally killed for ivory in 2011;[273]
- **Mammal declines in south-east Asia.** Regional declines in most species have occurred largely within the last 50 years, with hunting focusing on pigs, deer, monkeys, other arboreal mammals, and porcupines and other rodents. Many mammalian dispersers of large seeds and understorey browsers have been eliminated. Most of the hunting is now illegal, but law enforcement is generally weak;[274]
- **Mammal declines and extinctions in fragmented forests.** A study in Thailand found the near-total loss of native small mammals within 5 years from 10 hectare fragments and within 25 years from 1-56 hectare fragments,[275] while in a fragmented forest in Bolivia, 40% of large and medium-sized mammals were observed to decline as a result of hunting;[276]
- **Ecological disruption from hunting in central African forests.** *'Humans have hunted wildlife in Central Africa for millennia. Today, however, many species are being rapidly extirpated and sanctuaries for wildlife are dwindling. Almost all Central Africa's forests are now accessible to hunters. Drastic declines of large mammals have been caused in the past 20 years by the commercial trade for meat or ivory…a growing body of empirical data shows that trophic webs are significantly disrupted in the region, with knock-on effects for other ecological functions, including seed dispersal and forest regeneration.'*[277]

Next steps for further research

As noted at the beginning of this section, evidence from on-the-ground analyses indicates that the drivers of deforestation and degradation are interconnected and dynamic. The triggers and pathways[278] leading to forest damage and loss are multiple and hard to predict, and are themselves driven by underlying causes, including population growth, lack of secure land tenure, poverty, migration, land speculation, market trends, and weak governance and regulation.[279] Given the complexities, it is unsurprising that various studies have uncovered many catalysts and outcomes, including drugs as a driver of deforestation,[280] linkages between pulp plantations and the fashion industry,[281] threats to great apes in Africa[282] and tigers in Sumatra[283] from palm oil expansion, rising deforestation by small farmers in Brazil,[284] forest-related crime,[285] and the impact of civil war in the DRC.[286]

These factors and variables indicate the need for a more holistic approach to the analysis of the drivers of forest loss and damage, preferably at regional or even local scales. This would complement the focus of many current assessments, which tend to address a single commodity, such as palm oil or soybean.

Photo © Mattias Klum

5 Responses to the plight of tropical forests: an introductory overview

The preceding sections have sought to lay out the growth of knowledge on tropical forests, especially over the last decade. The advances that stand out are several:

- The burst of new science and spatial analysis which has greatly enhanced our understanding of the physical state of tropical forests, and their role in global ecological health and climatic regulation;
- The findings from ecology and conservation biology which show that the most precious asset of tropical forests – their ability to renew themselves – is progressively weakened when ecological functioning is impaired (e.g. through defaunation);
- The research that demonstrates that the tropical forest ecosystem services most highly-valued by humanity – the conversion of CO_2 into retained carbon, and the provisioning of water supply (including through rainfall generation) – are aligned with ecological functioning, pointing to both degradation and deforestation as even more damaging actions than was previously thought to be the case;
- The work by economists and others that is illuminating our grasp of the drivers of deforestation and degradation, especially the analyses of the supply and demand aspects of commercial agriculture and its role as an agent of tropical forest loss; and
- The pressing need for further analyses on the drivers and causes of forest loss and damage that recognise their inter-connectedness and variability at regional and local levels.

The sections that follow shift the focus of the report to assessment of responses - including analysis of the challenges that have been or are constraining action, and the opportunities to achieve lasting and effective tropical forest protection at scale. They also probe the extent to which current approaches are calibrated with the research findings outlined earlier.

Section 6 sets the scene through an exploration of the emerging *landscape-scale approach*. It seems clear to all involved in tropical forest protection that achieving both short and long-term mitigation and ecosystem services goals is dependent upon the formulation and implementation of measures at large scale. Forest landscapes (whether defined as biomes or ecoregions, or through alignment with jurisdictional boundaries) are increasingly seen as the appropriate framing to allow for significant progress to be made, within all of the responses reviewed below.

Sections 7–10 evaluate the range of initiatives and issues: REDD+; supply chains; the Bonn Challenge and restoration; conservation; sustainable forestry; new and recent international and regional initiatives, including the New York Declaration on Forests, the UN Sustainable Development Goals, and the Governors' Climate and Forests Task Force (GCF); and the enabling conditions that are necessary for the achievement of wise stewardship of tropical forests.

Nepal landscape. Photo: Sajal Sthapit EcoAgriculture Partners

6 The landscape-scale approach

Summary points

- The tropical forest landscape-scale and jurisdictional approach has great promise as a means to achieve significant mitigation, ecosystem protection and sustainable development success;
- Quantified targets for the multiple objectives are essential as a means to avoid the fulfilment of one goal at the expense of another;
- Projects will continue to play a critical role, and should benefit from inclusion within jurisdictional frameworks.

Introduction

Before the advent of REDD+, tropical forest protection was implemented principally through two interventions: protected areas, and small-scale projects. The former concentrated on conservation, financed by tropical countries themselves or international donors or a combination of the two. The project-based model tended to be focused on broader objectives: some were conservation-oriented, but the majority sought to achieve gains and improvements in the livelihoods of communities, generating revenues from the sale of agricultural and forestry products as well as obtaining support through overseas development assistance (ODA) programmes.

In the early 1990s, spurred by rising concerns over climate change, some ODA began to support climate mitigation alongside sustainable development and conservation within projects; and by the end of that decade, some projects were able to align with the requirements of the Kyoto Protocol's Clean Development Mechanism (CDM), which included provision for afforestation (tree planting on land with existing tree cover) and reforestation (tree planting on previously deforested or other non-forest lands). The arrival of REDD+ increased support for projects, and encouraged their creation and management by private sector developers as well as government, civil society and community actors. By contrast, protected areas have largely remained outside of REDD+.

Recent years have seen two further developments: the drive for action at large scale, and for a more integrated 'tropical land sector' within both REDD+ and the broader AFOLU (agriculture, forestry and land-use) framework.[287,288] These developments are in part a recognition of the dual need to protect forests and to catalyse a shift toward more sustainable agriculture and forestry across the tropics.

As a result, the *jurisdictional* concept (the definition of an area according to legal and administrative boundaries, from national to state and local) and the related *landscape-scale* (or *sustainable forest landscapes*) model are increasingly framing the thinking behind forest and other land use initiatives, particularly amongst multilateral and bilateral funds, institutions and agencies. Such approaches aim to encourage the development of a land-use strategy for a large area, where boundaries are agreed and activities fostered and encouraged in the furtherance of the multiple objectives of REDD+ and other forest management approaches. The landscape-scale approach is inherent in the vision of the World Banks BioCarbon Fund Initiative for Sustainable Forest Landscapes (ISFL), the Bonn Challenge on forest restoration, and the New York Declaration on Forests; and to a large extent it is informing thinking and decision-making in the supply chain context.

Jurisdictional and project-based models

In principle, the jurisdictional model introduces much-needed simplicity (for example on reference levels, additionality, leakage, and MRV requirements) and lowers transaction costs. Set against this, from the viewpoint of some private sector, civil society and community actors, the jurisdictional model might have some negative consequences: centralised procurement and disbursement processes have the potential to disadvantage small projects, stifle innovation, and lead to disempowerment at the local level. Such tensions between at-scale or top-down approaches (that impose relatively coarse-grained rules), and bottom-up solutions (that are less coherent in the collective sense, but more adapted to local conditions) are familiar from other areas of economic activity.

However, the jurisdictional and project approaches do not need to be mutually exclusive. Much work has been done to outline how projects might be *nested* within jurisdictional frameworks. Nesting is also seen as a way of capitalising on the known advantages of projects (principally their often more rapid development and entry into the implementation phase) whilst maintaining overall jurisdictional coherence.[289]

Landscape-scale tropical forest management: challenges and opportunities

While some tropical forest landscapes remain dominated by extensive primary or secondary forests, others have been partially developed, comprising a mosaic of commercial and smallholder agriculture, settlements and industrial facilities, roads and other infrastructure; all within or alongside the remaining forests.

From the development perspective, landscape goals are likely to focus on shifting the balance of activities away from destructive to more sustainable practices; for example, climate-smart agriculture, and agroforestry and the suite of sustainable forest management models instead of indiscriminate logging or clearcutting. *Multipurpose forest management* is the policy label often associated with such landscape strategies.

The need to provide support for this shift is recognised within REDD+, which deems a range of agricultural and forestry interventions as allowable (usually in the *reducing emissions from deforestation* category), so long as an emissions reduction outcome can be substantiated, in accordance with agreed baselines and monitoring, reporting and verification rules. The intended result is a forest landscape where, over time, emissions from forestry and agriculture decline, without negative impacts on livelihoods and prosperity.

The goal of securing full protection for forests to secure maximum mitigation and other ecosystem benefits is of course an intrinsic part of the sustainable development agenda, but requires a very particular focus. In REDD+ terminology, the relevant interventions principally fall under the *conservation* and *enhancement of forest carbon stocks* headings.

Tensions between landscape-scale objectives

This state of play is the backdrop to the assessment of effective interventions: the extent to which the range of priorities can be accommodated within the same forest landscape is a central question (for all of the policy responses reviewed in this section). Yet it is rarely[290] posed outside of the peer-reviewed literature, where 'land sharing' or 'land sparing' is much analysed.[291] The risks are clear: Sustainable development deemed to be sustainable, but which leads to forest conversion or degradation could undermine climate and ecosystem objectives: while an exclusive focus on mitigation and ecosystem protection without regard to the development needs and aspirations of communities will produce negative consequences in the other direction. There is also a need to ensure that conservation objectives (which can be distinct from those for mitigation and ecosystem protection) are reflected in decision-making.[292]

These challenges point to the need for national, regional and local land-use planning strategies that seek to account for all requirements, far simpler in theory than in practice. Pragmatism indicates that full forest protection is much more likely to be the loser than the winner in the allocation of lands. 'Sustainable development' alternatives can generate income from the sale of food, wood and other materials, alongside payment for emissions reductions – the attractive 'mixed revenue streams' sought by some donors and investors. By contrast, the potential revenue to be derived from forest protection is much more limited – unless and until payments are available for carbon retained, emissions avoided, and the provision of ecosystem services.

The role of quantified targets

One way forward is to embed quantified targets into sustainable forest landscape planning. These could include accounting for forest carbon stock maintenance (including additions from sequestration), and the range of water and other ecosystem services deliverables, alongside goals for agricultural and forestry outputs, and incomes and employment. Existing and proposed land-uses could then be assessed in the light of planned objectives. It may also be the case that the emerging 'landscape labelling' approach could provide a framework for embedding targets within outputs.[293]

Aligning REDD+, supply chains and restoration within landscape-scale action

Another landscape-scale priority relates to the recent commitments from several major companies (on the demand and the supply sides) to align their production or purchase of agricultural commodities in ways that reduce deforestation (see **Section 8**). The extent to which there could or should be synergies between REDD+ and such supply chain pledges is a live issue. A recent PwC report makes the case for large-scale collaboration, noting that a survey of REDD+ and Consumer Goods Forum members found unanimous support for much closer ties between the two communities.[294] This outlook is also implicit in the publicly available materials provided by the BioCarbon Initiative for Sustainable Forest Landscapes (ISFL).[295] At the minimum, coordination would seem desirable, given the need for coherence in tropical forest policy; and there is also a case for harmonisation at the implementation level (e.g. for carbon stock assessments). That is also the case for the Bonn Challenge and restoration.

In principle, tropical forest finance could be aligned with the landscape-scale approach as a means of funding multiple objectives: avoided deforestation; avoided degradation; sequestration (enhancement of forest carbon stocks);

conservation (of carbon, biodiversity, and ecosystem services); climate-smart agriculture; other low-emissions rural development (LED-R); and poverty alleviation and improved livelihoods. These objectives could also be aligned with supply chain demand, and with restoration goals. The aim would be to draw on advances already made in relevant areas of forest management. In practice this would mean adoption of several REDD+ elements (e.g. mitigation accounting, safeguards) as the basis for planning and implementation. The idealised model for forest finance in a targeted tropical forest landscape could therefore include:

- An overall REDD+ framework applying across the area, utilising the jurisdictional model for mitigation accounting (including accommodation of individual projects through the nested concept);
- Full adherence to REDD+ safeguards with respect to communities living in the landscape, and environmental and ecological land-use criteria;
- Overall legal responsibility, land-use planning and governance to reside with in-country institutions that have already received REDD+ readiness or other support for capacity building;
- Preferential supply chain sourcing from climate-smart agriculture and forestry (e.g. from certified plantations), on the basis of REDD+ quality assured and deforestation-free supply;
- The involvement of the conservation and restoration sectors in the management of existing and recovering forests in the landscape;
- Other LED development activity, perhaps set in the context of a national or regional green economy strategy;
- Payments for Performance (PFP) disbursed to producers of agricultural and forestry products, other LED outputs, and managers of conserved and recovering forests; and
- Donor country financing (including 'Phase 3' PFP at the national or regional government level for meeting REDD+ targets), via the range of multilateral and bilateral Funds (e.g. the Biocarbon Fund Initiative for Sustainable Forest Landscapes – ISFL, and the Green Climate Fund).

This is a more ambitious vision for forest finance than was originally envisaged; and arguably more robust than a focus on avoided deforestation alone. The jurisdictional model has the potential to simplify and lower transactional costs for emissions reductions and sequestration gains. From the supply chain and restoration perspectives, the model implies additional savings and diminution of risk because of the utilisation of REDD+ technical capital (e.g. for MRV). The alternative for those sectors (investment in the development of parallel systems and processes) is much more costly.

From the donor country perspective, the case for provision of finance is enhanced by private sector sourcing from the landscape, in effect a form of co-financing or public-private sector partnership in pursuit of sustainable development objectives.

The performance payments would be channelled into a range of interventions, including emissions reductions achieved through a shift to climate-smart agriculture and forestry, protection and improvement of water and other ecosystem services, and mitigation secured by forest conservation and restoration activities.

For tropical countries, the model provides a pathway toward a low emissions economy in ways that could increase prosperity and growth, without undermining sovereignty. In essence the model seeks the convergence of development and climate goals in the rural context, with overseas development assistance as an enabling factor. In principle, the contributions of the range of actors outlined above could help tropical forest governments to increase further their domestic efforts to manage their forests sustainably. This could occur through policy, regulation, increased investment of domestic resources and, for example, shifting the focus of agricultural policy to more sustainable practices.

The investment capital challenge in the landscape context

This exploration of an idealised landscape-scale model has so far largely looked at what might be termed the profit and loss account; the financing of operations for the production and sale of agricultural and forestry commodities, and other low-emissions development outputs, as well as public goods derived from emissions reductions, sequestration gains, and ecosystem protection. However, substantial upfront and on-going capital investment is also required.

Increased domestic investment in landscape-scale forest management, including protection and restoration, would have a fiscal impact for tropical country governments. Existing domestic and international public-sector funding streams are unlikely to be able to meet the challenge. The implication is that international and domestic public funds will need to be structured so as to leverage significant private finance, including from capital markets, the agriculture supply chain and local private actors.

Next steps

While the landscape-scale and jurisdictional approaches hold considerable promise, these propositions are still in an embryonic and largely untested phase.[296] In addition, their development requires agreement and coordination between many stakeholders, implying that lead times from conception to implementation may be considerable.

These caveats point to the wisdom of continuing support and encouragement for the project-based model. A recent report estimates that, in aggregate, some 400 REDD+ avoided deforestation projects cover almost 20 million hectares, the equivalent of the forest area of Malaysia.[297] While this is far short of the scale required to sharply reduce emissions from deforestation and degradation it is also a meaningful contribution, reflecting an enormous amount of individual and collective endeavour. And, when circumstances are favourable, project scale initiatives can demonstrate results relatively rapidly. These factors highlight the advantage, where possible, of nesting projects within jurisdictional frameworks. In some instances, project co-ordination and expansion could prove to be an effective early step toward a landscape-scale approach.

Choachí, Colombia. Photo: Carolina Figueroa

Photo: Chris Perrett, Naturesart

7 REDD+

Summary points

- More progress has been made to date than is generally recognised, particularly on the supply-side, through the development of REDD+ technical capital and capacity building;
- A target-based, landscape-scale and jurisdictional approach could deliver effective outcomes that meet REDD+ objectives;
- Synergies between REDD+, supply chains and restoration could improve outcomes and catalyse greater finance flows;
- Advances on these issues will not be sufficient without a significant (and long-term) increase in the REDD+ finance provided by donor countries and continuing improvements in the enabling environments of rainforest countries;
- The potential contributions of a range of mechanisms and instruments that seek to stimulate demand should be evaluated, recognising that the overall financing strategy will need to be a composite of approaches, within which leveraging private as well as public sector funds will be a priority.

Introduction

REDD+ is a response[298] to the under-valuation of tropical forests: it is *'an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development.'*[299] Originally conceived of as a means to incentivise reductions in emissions from tropical deforestation,[300] REDD+ (since 2010) now comprises five goals: *'reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries.'*[301]

The broadening of the mandate has created the potential for REDD+ to contribute to climate change mitigation, achieve sustainable development through low-carbon pathways, and alleviate poverty, whilst also conserving biodiversity and sustaining vital ecosystem services.[302] This in turn has fostered several new ideas, including the jurisdictional model and the sustainable forest landscapes concept, which have spurred the creation of new multilateral Funds that seek to harness the innovations as routes for achieving REDD+ objectives at scale.

Other significant new responses to the tropical forests challenge have taken place in parallel that affect the positioning of REDD+. The most notable are the Bonn Challenge and subsequent commitments to restore degraded tropical forest landscapes, and efforts by the private sector to achieve zero-net deforestation in agricultural supply chains that source from tropical regions. The extent to which there is or should be synergy between these developments and REDD+ is an on-going aspect of discussions.

A further element is the progress made on building the competency of REDD+. The rules, guidelines and toolkits for monitoring, reporting and verification (MRV) and for social and environmental safeguards are now largely in place. At the same time, the governance capacity of many in-country institutions has been strengthened, via the REDD+ readiness programmes of the Forest Carbon Partnership Facility (FCPF) and UN-REDD.

But perhaps the greatest increase in optimism has come as a result of Brazil's success in reducing deforestation by 70% between 2001-2011, although the rate has increased since then.[303] While the Brazilian success story is not directly attributable to the impetus generated by REDD+, the outcome does show the demonstrable success at scale which had previously been lacking; and what is achievable in a context of strong political will, institutional reform and public and international support.

These factors are grounds for a positive outlook: many of the components are now in place to realise the REDD+ vision. However, three significant hurdles remain. The first is the continuing struggle to finance REDD+, a challenge that embraces the mechanisms and instruments as well as mobilisation of sufficient funds to drive large-scale action. The second is the need for donor and tropical forest countries alike to renew their ambition and will to implement REDD+, particularly in the light of the findings from science outlined in **Sections 1-3**. The third is the often neglected issue of responses to demand-side challenges. While many of the proposed solutions outlined below hold much promise, unless there are provisions for stimulating demand for payments for performance, overall progress may well continue to be constrained.

The development of REDD+ to date

When the 21st Conference of the Parties to the UNFCCC is convened in late 2015 in Paris, REDD+ will have been in development for 10 years, and, for many, the rate of progress has been much slower than originally envisaged. However, given that this is the first ever attempt to internalise the value of tropical forests within the global economy, it can be argued that early expectations were unduly optimistic.

The technical capital of REDD+

Formal milestones[304] (see **Figure 1**) in the multilateral context include: the Bali Action Plan (2007); the framing of national forest monitoring systems (Copenhagen, 2009); definition of REDD+ activities, a framework for REDD+ readiness and the creation of agreed social and environmental safeguards (Cancun, 2010); key agreements on REDD+ finance, baselines, and safeguard information systems (Durban, 2011); progress on non-market approaches and co-benefits (Doha, 2012); and key decisions on monitoring systems, baseline assessments, monitoring, reporting and verification rules (MRV), and adoption of the elements of REDD+ required for results-based financing eligibility (the Warsaw Framework, 2013).

The milestones in this timeline represent significant progress – particularly the development of toolkits for monitoring, reporting and verification. These constitute the technical capital of REDD+, but because the processes have been incremental, their value tends to be overlooked or under-estimated.

Figure 1: The REDD+ timeline

2005

COP11 (Montreal): Papua New Guinea & Cost Rica ask for a new agenda item called "Reducing Emissions from deforestation": **Launch of a two-year process**

2006

COP12 (Nairobi): Agreement on a second workshop

2007

SBSTA26: Consideration of workshop reports & draft decision

COP13 (Bali): **Bali Action Plan**: Non-Annex I Parties to undertake measurable, reportable & verifiable NAMAs; REDD+ activities introduced; guidance on demonstration activities

2008

COP14 (Poznan): Paving the way for COP15…

2009

SBSTA29: Expert meeting on reference emission levels; draft decision for COP15

COP15 (Copenhagen): Methodological guidance on REDD+ activities, including: national forest monitoring systems required to estimate GHGs from forestry activities

2010

COP16 (Cancun): Cancun Agreements: guidance on implementation of REDD+ activities, including: national forest monitoring systems required to monitor and report on REDD+ activities

2011

COP17 (Durban): Guidance on forest reference emission levels and forest reference levels for REDD+ activities and on systems for providing information on REDD+ safeguards

2012

COP18 (Doha): Work Prog/ on results base finance under the COP to be resumed at COP19 / Coordination of support SBSTA/SBI / initiation of work on non-market approaches and methodological guidance for non-C benefits

2013

COP19 (Warsaw): **Warsaw Framework**: Guidance completed for FRELs/FRLs, and NFMS; more guidance on SIS and MRV and Drivers / Provisions for result-base finance and coordination of support

REDD+ Provisions, Rules and Modalities provided through decisions

Source: Sanz-Sanchez, M.J. 2014. Presentation to the Congo Basin Forest Partnership meeting, Brazzaville, October.[305]

The Three Phases of REDD+

As originally framed, REDD+ is designed in three phases. In Phase 1, a national REDD+ strategy is developed, supported by readiness grants (e.g. from FCPF or UN-REDD); Phase 2 sees the implementation of strategy, also supported by grants or other financial support for capability building, and enabling policies and measures (including some payments for emission reductions measured by proxies); in Phase 3, implementation continues, in some cases as a component of national (or state-based) low-carbon development strategies. This last phase is also envisaged as the point in the process at which REDD+ becomes fully operational, including the release of payments for performance (PFP).[306] These phases need not be sequential, or mutually exclusive, and a country may be in multiple phases at the same time.

Phase 1 is underway in most countries, with work largely focusing on strengthening forest protection capacity, driven by joint donor-government REDD+ readiness strategies, which draw on the already provided or pledged REDD+ driven multilateral and bilateral assistance that has contributed[307] or is likely to contribute to lower deforestation pathways in a number of countries, including Brazil, Guyana, Colombia, Peru and Liberia.[308]

While there is evidence of progress on REDD+ readiness in some countries,[309] factors which continue to impede progress include: lack of funding, human resources and experience within forestry and other relevant government ministries (e.g. for land-use planning and remote sensing analysis); inadequate legal systems; and lack of transparency and accountability. Governments in both developed and developing countries have found that these challenges are frequently under-estimated.[310]

Some countries are moving through Phase 2 in terms of strategy implementation (with less progress reported to date on the payments component), as indicated by analyses of funding allocations: 61% of donor government funding is currently channelled into readiness activities (in 80 countries).

While work on the framing and design[311] of Phase 3 mechanisms has been carried out, approval, adoption, and implementation still largely lie in the future, in part because required levels of readiness have yet to be achieved in many countries.[312] From the recipient perspective, however, the delay in the rollout of PFP is often attributed to donor country reluctance. The challenges to implementing payments for performance are explored below, under the heading *Key strategy and management challenges*.

REDD+ is also achieving some success on another key front, which is hard to quantify: the acceptance and adoption of REDD+ at the local level.[313] Recent reporting from the Brazilian Amazon,[314] Colombia,[315] Tanzania,[316] Kenya,[317] Nicaragua,[318] and Indonesia[319,320] suggests that some communities are embracing REDD+, for a range of reasons, above and beyond income derived from carbon finance. A range of benefits that enhance livelihoods are playing a part, including employment and the provision of education and healthcare within forest protection projects.

Progress on adoption is almost certainly a function of another area where REDD+ has made significant progress: the development and agreement of safeguards for indigenous communities within the Cancun Agreements.[321] These advances may also indirectly have played a part in stimulating the observed (but modest) increase in private sector purchases of REDD+ credits on the voluntary market, largely for corporate responsibility and climate leadership reasons.[322]

Jurisdictional and nested REDD+

The JNRI (Jurisdictional and Nested REDD+ Initiative) was announced by the Voluntary Carbon Standard (VCS) in Cancun in 2010.[323] The aim was to enable jurisdiction-wide emissions reductions accounting, and to ensure that carbon credits issued to 'nested' projects are recognised by jurisdictional authorities (whether national or sub-national).[324] The VCS published JNR requirements in 2012, with components on leakage and non-permanence following in 2013 and 2014.

JNR has steadily gained recognition and support, notably from the Governors' Climate and Forests Task Force (GCF) and The Nature Conservancy (TNC), and efforts are on-going to include Jurisdictional REDD+ Offsets within the California carbon market.[325] A recent report on lessons from Jurisdictional REDD+ and LED (low emissions development) provides valuable analysis of progress to date in eight jurisdictions, noting that all the programmes studied are at early stages, and are engaging with a wide range of challenges.[326] The lesson appears to be that the JNR model is unlikely to prove homogenous but that it can produce positive outcomes for forests.

Key strategy and management challenges

In the early REDD+ phase, the financing requirement was seen by some as the leading priority. More recently, attention has also begun to focus on strategy and management issues, catalysed by the expansion of REDD+ objectives and the accompanying development of jurisdictional and landscape-scale concepts. As noted in the New Climate Economy report, these new factors are driving the rise of a 'produce and protect' perspective,[327] in which shifts to sustainable agriculture and low-emissions development are prioritised alongside forest conservation. Robust and soundly-based strategic and management planning will be essential if these multiple goals are to be achieved.

The focus on strategy and management is likely to intensify further as the new findings from tropical forest science and analysis become more widely recognised. As well as produce and protect, REDD+ will also need to address emissions from degradation, the potential for CO_2 sequestration, and the importance of protecting and enhancing water services, all at the landscape-scale. Several challenges emerge from this context, as explored below.

REDD+ and key tropical forests

REDD+ has developed to date without a specific list or registry of tropical forests that are urgently in need of protection. It may be that the absence of such a list is a function of UNFCCC requirements for a generic system that identifies provable risk of forest loss (e.g. through the additionality, leakage, permanence and baseline reference levels concepts). In that context, provability is of greater significance than geographical factors. It is also likely that the broad focus on the three basins – Amazon, West and Central Africa, and South-East Asia – has been deemed sufficient from the strategic perspective.

Oceans West Papua. Aerial view of the Wayag Islands, located ten kilometres north of the equator and equally unique below and above water. Photo © Mattias Klum

The new outlook on mitigation and ecosystem services – especially when allied to the landscape-scale and jurisdictional frameworks – suggests that greater recognition of the specific characteristics of particular forests would now be beneficial. This is of particular relevance for intact (primary) forests, and already logged forests with the potential for recovery. A model can be envisaged that identifies and quantifies a range of specifics at the landscape-scale. These might include location, extent, carbon stocks, water and other ecosystem services, deforestation and degradation rates, past forest history and prospects for recovery, presence and distribution of indigenous forest communities and other inhabitants, drivers of forest loss and damage, and broader socio-economic and political factors.

Such a model could serve several purposes, including: greater visibility on the state of particular forests, and consequent prioritisation of actions; better understanding of the interplay of carbon and ecosystem services in specific contexts; and as a tool to develop management and protection plans (e.g. for the maintenance of high carbon stock forests). This last could go some way to redress one of the perceived weaknesses of the current REDD+ approach – the tendency for action to be catalysed at the point of deforestation risk ('the forest frontier'), rather than earlier in the process.

Identification of key tropical forests at the landscape-scale could also be valuable in the context of developing mitigation milestones. Each landscape might be a quantified unit in CO_2 terms, enabling local, regional, national and global REDD+ strategies to create targets with respect to deforestation, degradation and sequestration that would be traceable to particular areas of forest.

High carbon stock forests, protected areas and forests managed by indigenous communities

A core precept of REDD+ is that actions to protect forests need to be in response to proven threats, and additional: that is, they do not replicate actions that are already being undertaken. The additionality[328] concept has clear strengths but there are areas of concern where admissibility within REDD+ may, in practice, be constrained: forests in countries with low deforestation rates; formally designated protected areas and forests managed by indigenous communities; and forests with high carbon stocks.

For low deforestation countries, the way forward might be to begin to address the forest degradation challenge, in addition to supporting the consolidation of a development pathway that maintains low deforestation over time. Given what is now known about emissions from this source, continuing treatment of degradation as being of limited importance seems unwise. Factoring degradation into reference levels would bring a number of currently excluded countries into the fold. Such a move could be contentious, because data on degradation rates are widely seen as unreliable. However, new studies[329] utilising radar, lidar and optical instrumentation increasingly show that degradation can be measured. Perhaps a first step is to establish the overall state of knowledge on emissions from degradation on a geographical basis.

For formally designated protected areas (PAs), the constraints on entry into REDD+ may be a function of perception. In principle, deforestation and degradation in protected areas can and should be included within baselines. Equally, there is no explicit exclusion of protected areas within the current REDD+ framework. One recent study notes that views on inclusion or exclusion strongly vary, indicating that a lack of consensus may be the most significant barrier.[330]

A factor that may be influencing perspectives relates to current PA financing. Many already receive national and international funding) from channels outside of REDD+, which perhaps leads to an assumption that protected areas are secure and thus do not qualify for additional capacity building and Payments for Performance via REDD+. In practice, however, inadequate resourcing is commonly reported. This implies the need for assessment on a case-by-case basis. If deforestation and degradation are already occurring within PAs, or if threats can be proven, then the argument that they should be brought within the REDD+ fold gains strength.

Similar issues play out with respect to forests managed by indigenous communities. Several recent reports make the case for the forest protection gains of this approach, arguing that further significant advances in carbon and ecosystem maintenance could be achieved if resolution of tenure issues and greater finance flows were to be expedited.[331]

This still leaves some high-carbon stock forests outside of the REDD+ framework, where both deforestation and degradation rates are low. Despite the inherent difficulties, consideration will perhaps need to be given to financial mechanisms that recognise the importance of the maintenance of existing forest carbon stocks, regardless of reference levels.

Supporting effective REDD+ management models and approaches

Three management models appear to hold the most promise: protected areas; forests managed by indigenous communities; and projects run by private sector managers in partnership with governments, communities and civil society organisations. However, they are not at all homogenous: community management approaches in Mexico are different from those found in the Amazon Basin or South-east Asia; protected areas are on a spectrum from full governmental control through to those run under private management; and the partnership model is similarly varied. A valuable next step would be to absorb (and replicate) the lessons from innovative land-use designations and instruments that are beginning to achieve results, such as Mexico's community forest management laws[332] and Indonesia's Ecosystem Restoration Concessions.[333]

Synergies between REDD+, supply chains, and restoration

The potential synergies between REDD+, supply chains, and restoration constitute another area requiring careful strategic planning and management. Success in this context is likely to be dependent on the development of a credible and operational system for PFP, much more capacity building via existing REDD+ readiness programmes, and incentives for sustainably produced agricultural commodities.

Payments for Performance (PFP)

PFP (sometimes referred to as *results-based financing*, RBF) has long been envisaged as a component of Phase 3 of REDD. The 2013 Warsaw Framework includes agreement that donor countries should scale-up PFP as a key priority.

There are many challenges to overcome in implementing PFP, with the risk of double-counting as a leading concern for some donors, because of the difficulty of attribution of outcomes, where REDD+ readiness finance and PFP are being disbursed in parallel. Here we focus on a different perspective: the extent to which there should be a weighting of PFP toward those activities that generate the highest levels of mitigation.

As noted above, mitigation achieved from full (non-extractive) forest protection carries a handicap relative to emissions reductions achieved from sustainable agriculture and forestry, which derive a portion of their revenues from the sale of physical products. In general, the most extractive practices produce the least amount of mitigation, and vice versa.

Concomitantly, high levels of extraction generate the most revenues from sales of physical products (e.g. timber, agricultural commodities), and again, vice versa. In this context, non-extractive forest mitigation is also quite different from renewable energy, where the sale of electricity generated by solar, wind or hydro generates revenues and also achieves emissions reductions. One option might be to develop a PFP weighting that takes the range of revenue streams into account. PFPs deriving all of their revenues from sales of CO_2 mitigated could receive additional donor support as a means to level the playing field.

Resolving definitional challenges

As explored in **Section 7**, a number of definitional challenges constrain action on REDD+. These include a lack of clarity over the definition and probability of deforestation, and the absence of a clear working definition of degradation and its different states. It can also be argued that there would be benefit in having a definition of recovering forests that recognises the additionality of CO_2 sequestration as a result of appropriate management practices. It may be that the route forward on these issues is forest-specific rather than generic, although even attempting to quantify these factors within landscape-scale strategies could prove fruitful.

Financing options for REDD+

Introduction

There is broad consensus that current REDD+ finance flows (see **Box 4**) are far below the levels required to significantly reduce emissions from tropical deforestation and degradation. The multilateral and bilateral fast-start finance (FSF) commitments made by donor countries in 2009 have had some impact, but do not compensate for the absence of significant forest carbon credit purchasing through compliance and voluntary markets.

The FSF flows have largely been applied to capacity building (REDD+ readiness) in tropical countries, an essential but insufficient step. For most countries, the achievement of emissions reductions still lies in the future: the Phase 3 activities that implement changes in forest management that reduce deforestation and degradation. Those activities depend to a large degree on Payments for Performance, for which much larger sums are required.

Putting a scale to these sums is inordinately difficult, but the New Climate Economy[334] report suggested that donor countries should aim to provide US$5 billion of REDD+ finance per annum (the amount recommended by the 2006 Stern Review).[335] Another approach, purely for illustrative purposes, suggests that this could be an under-estimate. A rudimentary calculation,[336] on the basis of a price of US$5 per ton of CO_2, puts the cost of the 50% reduction in the emissions summarised earlier (see Grace *et al* and Houghton, **Table 3, Section 2**) in a range of US$18 - 20 billion a year, not so dissimilar to the estimate provided in The Eliasch Review (US$11 – 19 billion per year).[337] Perhaps the key point is that while robust estimates remain elusive, and inevitably gloss over the complexities of REDD+ economics, there is a very significant gap between the available and required levels of funding. As the NCE notes, even US$5 billion a year is *'at least a doubling of current annual financing of REDD+.'*[338]

Many proposals for bridging the funding gap have been made (see below), some linked to the likely shortfall between current INDCs (Intended Nationally Determined Contributions) and the emissions reductions required to limit global average temperature rise to 2°C in 2030. An assumption underpinning this thinking is that the cost of tropical forest mitigation is considerably lower than for many components of the fossil fuel challenge, and therefore determined and large-scale actions to protect forests could play a vital role during the period of transition to a low carbon economy. From this viewpoint, adequate levels of REDD+ finance are even more critical.

These are compelling arguments, but they have not yet catalysed significantly greater funding flows. While some of the impediments are a function of external macro-economic conditions (e.g. constraints on public sector financing deriving from the 2007-2008 financial crisis), other causes of the funding gap are perhaps a function of two issues: the early history of supply side difficulties, and weak demand for REDD+ forest credits. Both seem to be contributory to a lack of resolve, confidence and ambition within the donor community.

Recognition of supply-side progress

Perhaps one of the principal shortcomings of REDD+ to date is that, at inception, supply side issues were neglected, on the presumption that the key problem was provision of finance. The enabling conditions on this front are now far more favourable, as a result of the development of REDD+ technical capital and the investments in REDD+ readiness. While in absolute terms there is still a serious shortage of absorption capacity, REDD+ is closer to 'investment-grade' status than at any previous point in its history. However, it may be the case that awareness of supply-side progress has not yet been fully absorbed on the demand-side – amongst investors as well as donor countries.

Measures to stimulate demand

Considerable progress has been made in recent years on the development of an array of mechanisms and instruments that aim to channel REDD+ finance into forest protection. Many hold promise – but as components of a composite response, not as silver bullet solutions. The challenge now is to assess how the range of models, products and approaches can be configured, much as has been done with some success in the renewables sector. However, REDD+ finance mechanisms and instruments can only be successfully activated if there is sufficient demand; and without appropriately scaled incentives (e.g. through subsidy schemes and regulatory measures), demand will not materialise, and overall progress will continue to fall far short of REDD+ objectives.

Resolve, confidence, and ambition

The science outlined in **Sections 1-3** points very clearly toward the need for donor and tropical countries alike to renew their ambition and will to implement REDD+, if the tropical forest contribution to climate mitigation is to be achieved. Given the scale of the finance shortfall outlined above, it seems unlikely that progress can match climate imperatives without a gear-change in outlook. If available finance needs to at least double, this implies that instead of hundreds of millions of dollars, billions are required; plans for forest protection should be framed at many tens of millions of hectares; and mitigation goals should aim to reduce emissions by billions of tons of CO_2 per year, not tens of millions. Yet, at present, much REDD+ strategic thinking seems to avoid the need to address the challenge at a scale sufficient to make a real difference. This is in marked contrast to actions in some countries that seek to catalyse a radical shift to renewables, for example the transformation of the solar industry in Germany, California, and Australia.

Supply side progress

The optimism of the early REDD years was based on an assumption that money – flowing in large quantities from rapidly expanding carbon markets, through a single global treaty mechanism – could go a long way to solve the tropical forests component of the climate challenge. Both are yet to materialise. With hindsight, it is also likely that a number of other challenges contributed to slower progress than expected.

In its original guise, REDD was largely reliant on a project-based model, leading to concerns that economies of scale might not be achievable, and triggering concerns over funding efficiency and effectiveness. The factors that constrained REDD financing in the early phase included: the embryonic state of REDD technical capital (especially for MRV – the monitoring, reporting and verification rules and guidelines); inadequate safeguards and other enabling conditions; the absence of significant interest and involvement by companies in key supply chains; low confidence levels engendered by the apparent inability of initial efforts to produce demonstrable and large-scale success; the lack of a fully developed Payments for Performance (PFP) concept;[339] and the initially narrow focus of REDD on the 'avoiding deforestation' objective.

These challenges were largely recognised[340] by the time that Parties convened in Copenhagen in 2009, and a positive outcome from that meeting was the agreement to commence fast start (or interim) climate financing, including for REDD+. This in turn paved the way for the rise of multilateral and bilateral REDD+ funding initiatives. Since then, several additional developments have provided responses to those early constraints:

- *Expansion of REDD+ objectives.* The expansion in 2010 of REDD objectives to REDD+ laid the basis for a more holistic approach to the management of tropical lands that is more attractive for public and private sector finance than the formerly exclusive focus on avoided deforestation;
- *Technical capital and capacity building.* REDD+ technical capital has advanced considerably, including for MRV; and the Cancun safeguards and REDD+ readiness investments have fostered more receptivity to REDD+ in tropical countries, and strengthened their governance and other capacities;
- *Private sector participation.* Private sector participation, signally absent at REDD's inception, is now significant and growing, particularly through the Tropical Forest Alliance 2020 and other initiatives that are seeking to catalyse supply chain commitments and actions (see **Section 8**);
- *Payments for Performance.* The Warsaw Framework at COP19 committed donor countries to scale up Payments for Performance, a critical step that paves the way for a scale up of forest protection activity to meet emissions reductions targets;
- *Scale-models.* Jurisdictional and sustainable forest landscapes models and concepts have the potential to enable implementation at scale in ways that meet the expanded objectives, and lessen dependence on the project-based approach;
- *Success at scale.* Though not directly attributable to REDD+, Brazil's success in reducing deforestation by 70% between 2001-2011[341] has demonstrated that very significant progress can be achieved through domestic leadership with international donor support.

These advances on the supply side are grounds for a positive outlook, indicating progress toward a pipeline of fundable forest protection projects and programmes. And, while concerns remain on the absorptive capacity of current project-based and jurisdictional and landscape models, it is likely that an increase in REDD+ finance would catalyse rapid capacity expansion.

The current REDD+ finance landscape

The data in Box 4 indicate that commendable efforts have been made by donor and tropical countries to provide REDD+ finance but that the current funding trajectories imply a serious shortfall, relative to the sums required to meet mitigation objectives.

Box 4: The REDD+ finance landscape

REDD+ and fast-start finance

- Aggregate REDD+ pledges in the 2006-2014 period exceeded US$8.7 billion;[342]
- Nearly US$4 billion of this was pledged during the fast-start finance (FSF) period (2010-2012);
- Within FSF (which encompasses all aspects of climate mitigation), REDD+ accounted for 10% of the US$30-35 billion total.

Multilateral and bilateral funding

- Pledges channelled via the seven principal multilateral Funds totalled US$3.1 billion between 2008 and March 2014;[343,344]
- Four are either units of The World Bank, or are managed or otherwise administered by it: The Forest Carbon Partnership Facility (FCPF) Readiness Fund; FCPF Carbon Fund; the Forest Investment Program (FIP); and the BioCarbon Fund Initiative for Sustainable Forest Landscapes (ISFL);
- The other Funds are: The UN-REDD Programme, the Amazon Fund, and the Congo Basin Forest Fund (CBFF);
- Disbursements to date have largely been channelled into REDD+ readiness capacity building, but some of the Funds (notably FCPF Carbon Fund, UN-REDD and ISFL) are beginning to support larger-scale activities;
- The REDDX report notes significant lags between commitments and disbursements in seven countries;[345]
- While there are more than 20 REDD+ donors and 80 recipient countries, activity is relatively concentrated. Norway's[346] approach stands out, with pledges amounting to more than US$3.5 billion (41%), followed by the US (12%), Germany (10%), Japan (7%), and the UK (6%);
- Together these five countries account for 75% of all international pledges of REDD+ finance to date;
- Donor countries fund through a variety of mechanisms, including multilateral and bilateral Funds;[347]
- Indonesia and Brazil collectively receive 40% of allocated REDD+ finance, with the remainder distributed across 71 other recipient countries;[348,349]
- Tropical countries also fund their own domestic efforts, although the available data are incomplete. To date, the REDD+ Partnership reports US$1.57 billion in domestic investments across 39 countries.[350]

Green Climate Fund

- The UNFCCC's Green Climate Fund[351] is currently in formation, and the first pledging conference in November 2014 yielded $9.3 billion, rising to $10.4 billion following pledges made at COP 20;[352]
- The GCF is a part of the proposed architecture for future climate agreements, and is seen as a key distribution channel for a portion of the US$100 billion a year of climate finance to be mobilised by 2020, which Parties endorsed at the Copenhagen meeting;
- While REDD+ and other land-use focused mitigation programmes are in alignment with GCF goals and purposes, the guidelines and frameworks on how the CGF will provide finance for REDD+ are currently in development.[353,354,355]

2015-2020 and beyond: funding estimates and options

- Two estimates of REDD+ finance required for the 2015-2020 period give ranges of US$4 – US$16 billion[356] and US$19 – US$31 billion,[357] both per year;
- The data should be treated with a great deal of caution; these are topdown estimates, based on emissions reductions required, which do not address the critical question of existing and potential absorptive capacity on the supply side.

Mexico. Photo: Mr Theklan

Measures to stimulate the demand side

On the demand side, the actual or potential sources or types of REDD+ finance that are currently available or under discussion can be grouped under four headings:

- Overseas development assistance (ODA) contributed by donor countries, through their bilateral agencies, or via multilateral Funds;
- Subsidies provided by donor countries or tropical governments for forest protection purposes, through a range of mechanisms and instruments;
- Purchases of forest carbon credits through compliance or voluntary markets; and
- Support for forest protection by companies involved in agricultural commodity supply chains.

A range of approaches and instruments that seek to stimulate demand through one or more of these finance sources are either in pilot phases or under discussion, including funds,[358] loans,[359] letters of credit,[360] bonds,[361] various EU financing options,[362,363] innovations in biodiversity financing,[364] and pooled public-private sector funding concepts.[365] Some illustrative examples are given below.

Perhaps the key lesson to be drawn from past and present efforts to stimulate demand is that one source alone is very unlikely to bridge the funding gap. Success in this undertaking would seem to depend on a composite or portfolio approach in which all sources will have a significant contribution to make. It may well also be the case that a degree of mutual dependence (for example via co-financing approaches) will be necessary, implying the need for co-ordination and co-operation at the strategic level. Measures that can successfully leverage both public and private sector funds are likely to be especially valuable.

Mechanisms and instruments

Jurisdictional REDD+ Bonds

A recent paper[366] outlines how Jurisdictional REDD+ Bonds could be designed to access private finance, and to provide a fiscal incentive for tropical forest countries to invest in sustainable agriculture and forest protection within jurisdictional and landscape-scale frameworks. The Bonds would be issued by tropical country governments, drawing on multilateral support where country credit ratings would be too low to attract investor interest.

A portion of donor REDD+ finance would be applied to cover a part of the coupon/interest costs on a REDD+ Bond, thus reducing tropical country borrowing costs, seen as currently in a range of 5-7% on a long-term US$ basis. Revenue generated from the sale of Bonds would provide the upfront capital to help build a landscape-scale green economy, from food and wood processing facilities to the development of small farmer extension services, capital items required for forest monitoring, training and other aspects of capacity building, credit programmes, and support for indigenous communities.

A Price Guarantee Approach for REDD+

A price guarantee approach to bridging the REDD+ finance gap has been outlined in a recent paper by Ruben Lubowski and others.[367] This suggests that suppliers could offer potential buyers of forest carbon credits a guaranteed price at which they would have the right, but not the obligation, to access a designated pool of emissions reductions up to a specified contract expiration date. Buyers would need to make an up-front payment to secure the price guarantee (or long-dated ‘call option’). The option (as in other market contexts) would be priced below current market returns, yet the revenues received by sellers could nevertheless provide significant amounts of much-needed investment. On the buy side, purchasers would help limit their future potential compliance obligations in the event that prices were to rise higher, and gain an asset that could rapidly appreciate, depending on future climate policy developments.

International as well as domestic donor country commitments

Considerable attention is likely to be focused during 2015 on the expected gap between INDCs (Intended Nationally Determined Contributions) and the emissions reductions required to limit global average temperature rise to 2°C. One forthcoming paper proposes 'dual contributions' by countries offering INDCs, in which pledges are made toward international as well as domestic targets. It argues that a European Union pledge along these lines could achieve an additional reduction of 1 billion tons of CO_2 per year in the period 2020-2030 through this route.[368]

Assessing the utility and potential of subsidy-driven models

One starting point for assessment of subsidy options might be to apply more scrutiny to the question of how donor countries could pump-prime tropical forest mitigation actions, as they have done for renewables. As noted in the Valuation section (see **Section 4**), there are already several examples where governmental finance can be seen as a form of subsidy in order to achieve tropical forest goals; for example, forests that are protected out of public funds for water services. It could also be argued that Norway's agreement with Liberia and Brazil's provision of public sector expenditures for forest management and law enforcement also contain elements of subsidy.

There are other sectors of the economy where actions have been taken to reduce high capital costs and policy uncertainty (significant barriers to private sector investment), through long term government intervention. For instance, in the context of fossil fuel mitigation, government subsidies have been provided in a range of forms. In Germany for example, while 95% of investments in residential solar photovoltaic installations in 2010 were made by the private sector, over half were supported by concessionary loans from public banks.[369] In Europe and the USA support for renewable energy infrastructure development has been channelled via Feed-in-Tariffs (FIT), Renewable Energy Certificates and the use of tax credits. Arguably, Feed-in-Tariffs represent a form of Payment for Performance (for the generation of green kilowatt hours of electricity). Such approaches have been adapted to specific purposes. The UK's FIT is an environmental programme that aims to promote the use of small-scale renewable and low-carbon electricity generation technologies. If a householder, community or business has an eligible installation, FITs pays them a tariff for the electricity they generate and a tariff for the electricity they export back to the grid.[370] The related UK Renewables Obligation (RO) is the main support mechanism for larger-scale renewable electricity projects that places an obligation on UK electricity suppliers to obtain an increasing proportion of their supply from renewable sources.[371]

It may be the case that aspects of these (and other) schemes could be applied to the problem of tropical forest CO_2 emissions mitigation, with the aim of leveraging private capital in support of REDD+ and low-emissions development. Such approaches – in combination with existing REDD+ policy and financing initiatives, and via alignment with voluntary and compliance carbon markets that currently transact forest carbon credits – could perhaps provide a level of consistency (if not certainty), that has in the renewable energy context been used to good effect to improve projects' credit worthiness, and therefore bankability.

There are many variables to be assessed, including the differences between the generation of electricity from renewable sources and the management of tropical forests for REDD+. Nevertheless, the core idea – that governments could consider subsidy-based options to incentivise forest management on a payment per ton of tropical forest CO_2 abated basis (with US$5[372] widely seen as the current price point) seems to be likely to garner further attention.

The role of carbon markets

Enthusiasm for the effectiveness and capacity of carbon markets waxes and wanes, much to the dismay of those who considered them to be the panacea to addressing efficiently the benefits of transformation at the marginal cost of abatement. Within that context, there has equally been a long debate about the potential for forest-based carbon offsets/credits to disrupt the carbon market. While the initial concerns around permanence and durability have to some extent been addressed, the sheer potential volume of REDD+ credits still has the capability of diluting the efficacy of other compliance mechanisms. At the moment, and indeed for the foreseeable future, supply far outstrips demand (see **Box 5**).

Box 5: REDD+ and carbon markets

- Voluntary offset transactions for REDD+ projects (including logging-based regimes under the 'improved forest management' heading, as well as conservation, afforestation and reforestation projects) are estimated to currently stand at US$0.9 billion, with market volumes of US$216 million in 2012;[373]
- In that year, 97% of the forest carbon transactions were purchased by the private sector: the majority of buyers (67%) were multinational companies;
- Investment in REDD+ is dominated by a few large-scale projects, with Verified Carbon Standard (VCS) data indicating that 76% of the total estimated annual reductions are generated by just ten projects (out of 89);
- On supply and demand, developers reported that they were unable to find a buyer for 30 $MtCO_2e$ in 2012 – a volume that would have doubled market size if sold;
- The five-year supply pipeline is estimated at US$10.7 billion, vastly greater than current sales;[374]
- Yet this is a tiny fraction of the emissions from deforestation and forest degradation that need to be avoided.

The reasons for lack of progress in achieving tropical forest CO_2 mitigation by means of market based systems are both numerous and substantive. They include: current over-supply of project-based forest credits in voluntary markets, exclusion of avoided deforestation and degradation from the CDM, exclusion of forestry and land-use change offset credits from the EU ETS, uncertainty over the future role of tropical forest credits within regional and international carbon markets, and lack of movement toward the establishment of other compliance markets.[375]

These constraints lead some to conclude that markets will continue to be of marginal significance; and that as a result, all efforts should be focused on innovations in public financing. An alternative perspective is that buyer confidence is partially a function of supply-side success, and as a result they are likely to become more active as the landscape-scale, jurisdictional and PFP approaches and models are developed and implemented. However, such supply-side success is entirely dependent on there being a consistent demand, whether regulatory or voluntary, and at the moment, such demand is at best fragmentary and vestigial.

Such a view perhaps calls for a re-assessment of one of the ideas advocated by some during the early phase of REDD+: the argument that forest carbon credits should not be fungible; that is, it should not be allowed to substitute one contract of forest carbon with one contract of energy/industrial carbon in a market, either for reckoning net carbon positions, or (ideally) right through to settlement and delivery. It could be maintained that the landscape-scale and jurisdictional frameworks will create a stronger verifiable and visible supply chain for credits than is the case when they are sourced from a multiplicity of projects. However, if non-fungibility is the *sine qua non* for a viable forest carbon market, so too probably will be the agreement that the carbon budget against which the carbon credits would be retired should represent an additional commitment by countries.

Next steps for REDD+

While REDD+ faces many challenges, it is also the case that the investment in REDD+ has been considerable, has broadly remained true to the spirit of the original goal (creating financial value for the carbon stored in forests), and has laid a basis for the operational phase. This phase is already bearing fruit, especially in light of the advances made by many tropical countries toward REDD+ readiness, and the rise of the landscape-scale and jurisdictional concepts and frameworks. In addition, it can also be argued that the value of the technical capital created – the incremental progress in the toolkits, from Bali to Warsaw – is frequently under-estimated.

Of the several next steps required, some are continuations of existing actions, for example the need for on-going capacity building via REDD+ readiness programmes, and further refinements to MRV and PFP aspects. For new developments, a key priority is greater clarity on the relative weighting accorded to each of the REDD+ objectives within particular tropical forest landscapes, ideally expressed as quantified targets. This is of particular importance for mitigation and ecosystem goals, because there will be a tendency to favour the suite of agricultural development models, as these produce food and other materials and outputs, and sales and revenues within existing domestic and export markets.[376]

There is a risk that jurisdictional and landscape-scale approaches foster mosaic farming and other productive rural economy land-uses, while not simultaneously achieving the mitigation and ecosystem services outcomes that are central to REDD+ (and landscape-scale restoration). This is an explicit trade-off that has, as yet, received little attention.

Quantification of objectives is also important with respect to REDD+ finance: as the weighting of targets will vary from landscape to landscape, donors and investors seeking particular outcomes will be able to use data from targets to identify projects (or jurisdictions) which match their portfolios, in turn leading to greater confidence on where and how to channel REDD+ resources.[377]

Looking beyond objectives and management, three additional priorities can be seen. The first is the need to ensure that high carbon stock forests (including those in protected areas and under indigenous community management) – and recovering forests with significant sequestration potential – are able to take advantage of the benefits that REDD+ confers. This is likely to require progress on the definitional challenges highlighted in **Section 6**.

A second priority is to shift REDD+ toward convergence with supply chain and restoration initiatives, especially at the landscape-scale. If this can be achieved, the synergies are likely to include economies of scale (for example on MRV costs), greater opportunities for pooled or integrated financing strategies, a more compelling proposition for private capital, and increased supply of deforestation-free agricultural commodities.

A third priority is for renewed scrutiny of the potential utility of a range of financial mechanisms and instruments to stimulate demand. Jurisdictional REDD+ Bonds and other concessional finance products, price guarantee schemes, new approaches to subsidy-based sources, international as well as domestic donor country commitments, and renewed attention to the role of forest credits within carbon markets may help to leverage more significant flows, including additional commitments from REDD+ donors, and re-allocated domestic funding within tropical countries.

At this stage in the development of REDD+ it is challenging to signpost the optimal routes forward with any real certainty; this report seeks to highlight options that may help to bridge the funding gap, rather than providing specific recommendations. At the same time, it seems clear that more collaboration between REDD+ finance innovators could be beneficial: and, if the case for the composite or portfolio approach is accepted, then greater joint endeavours in this regard will be essential.

However, while efforts to stimulate demand hold promise, the overall outlook for REDD+ continues to be clouded by a significant degree of uncertainty over prospects for assured long-term financing of REDD+, with as yet no critical mass behind any of the propositions described above.

The funding gap – of at least double currently available finance – will, if not bridged, prevent the scale of transformation required to achieve adequate levels of forest protection within tropical countries. Yet, because of advances on the supply side, the transition from the status quo to the achievement of tropical forest mitigation and ecosystem services goals is within grasp.

This is the context within which the decision-making processes of donor and tropical countries over REDD+ is taking place. Yet the current absence of clarity over long-term REDD+ financing appears to run the very real risk of putting progress toward the transformation of tropical forest protection in jeopardy. If funding remains at less than half of the level required, then emissions reductions and ecosystem services protection achieved will also be likely to undershoot in parallel. The consequences would include further shrinkage and weakening of the tropical forest estate as a result of continuing deforestation and degradation, and diminishing sequestration, loss of water services, more defaunation and, of course, higher temperatures.

While donor and tropical countries seek to resolve long-term REDD+ financing certainty, there is a strong argument for short and medium term actions to be expedited as rapidly as possible. A key and immediate priority could be to progress the implementation of an integrated approach to sustainable forest landscapes, drawing on all possible existing financing mechanisms – whether donor finance, company commitments, and local and national institutional funding.

Photo: Raffaela Kozar, EcoAgriculture Partners

8 Supply chains, restoration, and conservation

Summary points

- Efforts to develop deforestation-free supply chains are making good progress, but need to move more rapidly from the commitment to the implementation phase;
- Other supply chain priorities include expansion beyond soy, beef, palm oil and timber, and the identification of alternative lands for production that meet rigorous carbon and biodiversity criteria;
- For restoration, the key question relates to purposes: what should degraded forest landscapes be restored to? Quantified targets that balance objectives would help bring clarity to intent and delivery;
- Measures to ensure that climate mitigation and ecosystem services recovery are not overlooked within restoration initiatives also need to be taken;
- For conservation, the under-valuation of carbon and biodiversity services provided by protected areas remains a serious concern; the eligibility of protected areas for REDD+ funding should be revisited;
- A further priority is the urgent need to devise policy responses that address the role of defaunation as an agent of forest degradation.

Supply chains and tropical forests

The concept of sustainable development has been at the heart of international discourse over the reconciliation of development and environment needs and goals since publication of the Brundtland Report in 1987. From a tropical forests perspective, two post-2000 developments stand out: a step change in the quality and clarity of scientific guidance, led by the IPCC's 2001 report and the synthesis of findings on the decline of global ecosystem services presented in the Millennium Ecosystem Assessment (2005); and the steadily increasing engagement of companies operating within supply chains that are driving deforestation.[378]

While the transformation of supply chains is still a work in progress,[379] a number of multinational companies have committed to sustainability goals and practices within their businesses, and are demonstrating leadership. In some cases this has led to specific zero-deforestation commitments by leading companies. Tropical forests are at the heart of much of this activity, because of their criticality within efforts to tackle climate change, and the dependency of supply chains (and the consumers they serve) on sourcing production from the tropical region.

Next steps include accelerating the inclusion of the majority of private sector companies within the relevant sustainability initiatives and standards; and ensuring that the rules and criteria underpinning current sustainable production plans and actions are fully aligned with tropical forest protection.

Leading supply chain initiatives

Collaborations such as those formed by the Consumer Goods Forum (CGF)[380] and the Tropical Forest Alliance 2020 (including its pilot project in West Africa)[381] are playing a significant role in the transformation of supply chains, in tandem with a wide range of voluntary initiatives that seek to encourage sustainable production, including: the Roundtable on Sustainable Palm Oil (RSPO); the Roundtable on Responsible Soy (RTRS); the Roundtable for Sustainable Biofuels (RSB); the Global Roundtable on Sustainable Beef (GRSB); the Leather Working Group; and the Banking and Environment Initiative.[382]

The impact of supply chains on tropical forests and recent responses

A new study, building on a wave of other recent research, confirms the rise (since c.1990)[383] of internationally traded commodities as a driver of tropical deforestation, finding that c.33% of deforestation (from beef, soy, palm oil and wood products) in eight countries (Argentina, Bolivia, Brazil, Paraguay, Democratic Republic of the Congo, Indonesia, Malaysia, and Papua New Guinea) was embodied in exports, mainly to the EU and China, with the export-share increasing for every country, except Bolivia and Malaysia.[384] The overall share of deforestation attributable to commercial agriculture (domestic consumption plus exports), as cited earlier, may be as high as 71%, although more peer-reviewed research is needed to test the proposition.[385]

Supply chain responses on internationally traded commodities are most visible (and have been most thoroughly chronicled) for soy and beef (in the Brazilian Amazon), and palm oil and paper and pulp (in Indonesia). For soy, 2006 saw the start of significant action, with the publication of a Greenpeace report[386] and subsequent commitments by Brazilian soy producers and international commodity traders (including the G4 cattle moratorium)[387] to cease planting and sourcing from lands deforested after that year. Beef followed a similar pathway, following a 2009 moratorium by Brazil's major cattle distributors and processors on the purchase of beef from any ranch that expanded grazing land at the expense of forests.

Most commentators agree that the actions on soy and beef contributed to the sharp decline in Brazil's deforestation rate since 2005.[388] But other factors have also played critical roles, most notably a range of legal measures clarifying tenure and land designations,[389,390,391] strong monitoring and enforcement, and the mobilisation of civil society. For soy, a recent paper argues that extension of the moratorium beyond 2016 is essential.[392]

The history of supply chain events for palm oil is both different, and more recent. Although efforts to reform palm oil production can be dated back to the formation of the Roundtable for Sustainable Palm Oil (RSPO) in 2004, the significant changes have occurred since 2010, catalysed initially by a Greenpeace campaign focused on a single Indonesian company, Golden-Agri Resources (GAR), which announced a pledge to eliminate deforestation from its palm plantations in 2011.

This was followed in 2013 by a pledge by Wilmar[393] to end all deforestation in its palm oil and other supply chains, including from third parties; a broadening of the mandate that GAR matched in 2014. Another milestone was reached in July 2014 when Cargill made a similar commitment (subsequently expanded to include all deforesting products within its operations, via an announcement at the UN Climate Summit;[394] Mars[395] and Pepsi[396] also made commitments to reduce deforestation earlier in the year). Others have followed suit, including IKEA,[397] Kellogg's, Johnson & Johnson, Hershey's, Safeway, and other consumer goods companies and retailers who have announced their own responsible sourcing policies for palm oil, and in some cases, for other global agricultural commodities.

As the three leading pledgers (Wilmar, GAR and Cargill)[398] collectively control 60% of globally traded palm oil (perhaps as much as 96%)[399] the potential impact is large. One study estimates that if all the commitments are implemented, the implied annual emissions reductions are equivalent to taking more than 400 million cars off the road for a year.[400]

Efforts to reduce or eliminate deforestation caused by plantations producing wood for paper and pulp have been developing in parallel to the palm oil initiative, notably the 2013 commitment by Asia Pulp & Paper (APP). This aims to achieve a goal of zero deforestation in its supply chain, including provisions for avoiding the conversion of high carbon stock and high conservation value forests, working more closely and transparently with local communities affected by new plantations, and allowing independent audits of its policy by credible environmental organisations.[401]

Challenges ahead

Broadening out deforestation-free supply chains

For some of the outstanding challenges, measures are in the early stages of formation: these include the TFA 2020 Africa Initiative which seeks to address sustainable sourcing of palm oil in Africa in advance of the expected expansion;[402] and the thinking that is going on to unify sustainable sourcing across Latin America and globally,[403] perhaps utilising networks such as the Governors' Climate and Forests Task Force (GCF).[404]

A further priority is for a comprehensive approach to the sourcing of paper and pulp; while the APP commitment is a big step forward, it is far from being the only company in the sector, and Indonesia is not the only source. The issues here are challenging (see below), because while there is a compelling case for the expansion of plantations producing wood, as a response to forest degradation (avoiding the need to source from natural tropical forests), there is also a strong case for these to be sited on lands with low carbon and biodiversity values, and without significant forest recovery potential.

Further strategies and actions are urgently required to address supply chains beyond soy, beef, palm oil and timber; and to expand the focus onto a wider range of countries.

The case for degradation-free as well as deforestation-free supply chains

The new findings on emissions from degradation that are attributable to selective logging suggest that development of a plantation-sourced *degradation-free* concept is desirable. This could be utilised within supply chains, much as 'deforestation-free' is now routinely described as the goal in the context of beef, soy and palm oil. See **Section 9** for further exploration of this option.

Identifying alternative lands for production

'Deforestation-free sourcing' pledges conceptually imply not only that sourcing can be switched to available alternative lands (low in carbon and low in conservation value), but also that the tools exist for the necessary assessments to take place.

These assumptions are yet to be fully tested, with intense debate around three principal issues: the definition of areas with 'high-carbon stocks' (HCS) and 'high conservation value' (HCV); and the 'zero-net deforestation' (ZND) model. If switching is to occur without perverse consequences, then the areas for deforestation-free sourcing need to be low in carbon and biodiversity attributes. At present, the basis for decision-making on these issues is unclear, with one major study commissioned (but not yet published).[405,406] The ZND model is premised on the assumption that as long as the *net* difference (existing natural forest loss *minus* new forests to replace them) is positive then the 'deforestation-free' label can be legitimately placed on the resulting products.[407] These issues have generated a stream of science,[408] commentary,[409,410] claims[411] and counter-claims,[412] reinforcing the need for a clear and agreed definition of forest.

The role of civil society

Civil society is widely seen as playing an invaluable role (including by the private sector), on several fronts: investigations[413] that shed light on deforesting practices; contextual overviews;[414] the mobilisation of community-based support; effective communication of the issues and imperatives to governments, the private sector,[415] and the global public; and involvement in negotiations on the resolution of problems. Looking forward, civil society is likely to remain integral to supply chain solutions as attention switches from corporate commitments to implementation.

Integrating supply chain action with green economy initiatives

Achieving a balance between product-driven and landscape-scale approaches is a key priority for supply chains, as is clear from the choices faced by companies as they seek to identify alternative lands for production. One route forward is for supply chain initiatives to actively participate in the development and implementation of green economy plans, now being developed at national or sub-national levels by a number of tropical countries.[416] As the *New Climate Economy* report[417] makes clear, there is a need to see tropical land use holistically, because needs and demands for forest mitigation and ecosystem services, food, other materials, and water all converge in the same landscapes.

Implementation of commitments

More broadly, though progress on supply chains is noteworthy, the inevitable gap between commitment and demonstrable impact on the ground needs to be closed as swiftly as possible to avoid scepticism, loss of credibility and barriers to entry for others.

The Bonn Challenge and forest restoration

Before the start of this decade, calls for serious consideration of large-scale forest restoration were rarely heard within international tropical forest dialogues and negotiations. But since 2010, a step change in awareness of the potential and opportunities has occurred, starting with the setting of the CBD's Aichi targets in that year, which include a goal of restoring 15% of degraded ecosystems by 2020. During the same period, the Global Partnership on Forest Landscape Restoration (GPFLR)[418] began work to build on the Aichi goal, which led to the Bonn Challenge[419] call, in 2011, for the restoration of 150 million hectares of degraded forest landscapes by 2020. A further development was the launch of the BioCarbon Fund Initiative for Sustainable Forest Landscapes (ISFL) in November 2013, to which the US, UK and Norway committed $280 million.[420]

The scale of ambition significantly increased in 2014, with the commitments announced in the New York Declaration on Forests at the UN Climate Summit. This affirmed support for the Bonn Challenge goal, and also for a new target of restoring an additional 200 million hectares by 2030. At the same time, several countries made new pledges: Ethiopia (22 million hectares); DRC (8 million hectares), Uganda (2.5 million hectares), and Guatemala (1.2 million hectares).[421] Encouragingly, some new commitments involve partnerships between governments, the private sector and civil society. One of these, announced at the COP 20 meeting in Lima seeks to

Butterflies in Borneo. Photo: Yalda Davis restore 20 million hectares in Latin America by 2020, backed by $365 million from five impact investors.[422]

The Summit also saw the release of the *New Climate Economy* (NCE) report, which includes three recommendations on land recovery opportunities: the restoration of 150 million hectares of degraded agricultural land into productive farming, including agroforestry; endorsement of the Bonn Challenge goal; and a call for an additional 200 million hectares of forest landscape restoration by 2030,[423] noting that the target is needed *'to catapult restoration on to the global policy agenda, raise awareness of restoration's benefits, trigger active identification of suitable areas for restoration, create enabling conditions, and mobilise the human and financial resources needed for restoration at scale.'*

What should degraded forests landscapes be restored to?

As hoped for by the NCE, the effect of 2014 commitments already seems catalytic: some early policy contributions highlight the potential of forest recovery to significantly reduce existing levels of atmospheric CO_2,[424] a point highlighted by two major articles in mainstream media.[425] These responses might lead observers to conclude that recovery for climate mitigation and related ecosystem purposes will be the principal focus of restoration strategies, with natural regeneration at scale as the priority intervention.

While some[426,427] are seeking to advance restoration along these lines, overall policy is likely to see forest recovery (and natural regeneration) as one of the options, alongside a range of other land-uses.

These include: the shift from unsustainable to climate-smart agriculture; the conversion of forests (to deforestation-free production) that are deemed to be too degraded for recovery to be viable; reduced impact logging and plantation forestry; and agroforestry. There are good arguments for the accommodation of these approaches at scale. But given the current extremely weak market demand for forest credits, it is not improbable that revenue-generating food and wood production will be prioritised over critical ecosystem services, which do not produce tangible, short–term financial returns (an issue that is explored further below).

Pooled approaches in which the former subsidise the latter will help, but without a determined approach, policy and plans are unlikely to safeguard the large tracts of recovering secondary forests that have the potential to deliver serious sequestration benefits. On a positive note, putting forest regeneration and protection at the heart of the restoration approach would increase the alignment with REDD+, enabling sharing of technical capital and resources.

One issue that is unquestionably common to both the restoration and REDD+ agendas is the need for quantified targets, within both land-use planning and implementation processes. The potential for environmental recovery within many degraded forest landscapes will be very significant; but for this to be realised, ecological assessments that quantify potential sequestration and other ecosystem services gains will be essential.

Challenges and next steps

Any assessment of restoration challenges at the current time is inevitably tentative, given the paucity of information in the public domain on how restoration commitments will be implemented. Nevertheless, a preliminary perspective can be framed around four headings: the need for clarity on restoration objectives; achieving balance in the portfolio of land-uses; implementation; and the identification of effective interventions.

Clarity on restoration objectives and balancing land-uses

As with REDD+, there is the danger that objectives will be assumed rather than clearly stated and embedded within landscape-scale strategies and plans. This leads to the question of balance, and the requirement to accommodate the range of land-uses. These can be seen broadly as falling into three categories: commercial agriculture; multipurpose forest management that seeks to shift agriculture and forestry onto a climate-smart and low carbon footing; and forest recovery for climate mitigation and ecosystem services goals.

For commercial agriculture, the various initiatives to move supply chains to deforestation-free production will play a key role: degraded forest landscapes will be targeted as potential lands that enable sourcing to switch, where carbon stocks and conservation values are low (and forest recovery is infeasible). Decision-making will also need to assess 'carbon leakage' in a broader terrestrial sense. Some (if not most) degraded forest landscapes include areas within them that were deforested in the past, and are now scrub or grassland. In principle, such lands would seem ideal as the basis for deforestation-free agriculture. However, a recent study indicates that such lands may in some cases hold significant carbon stocks.[428]

The difficulties inherent in balancing land-uses with respect to multipurpose forest management and forest recovery are, perhaps, the most formidable of all the restoration challenges.

At first glance, the instinct for sensible compromise would indicate that an 'equal weighting' approach is reasonable: for example, the 'sparing' of a hectare of degraded forest for every hectare converted to agriculture and forestry. This might be appropriate in an already heavily cultivated tropical forest landscape, but would be likely to lead to significant mitigation losses in contexts where food and wood production are currently minimal.

From one perspective, the fear is that restoration could lead to an agriculturally dominated landscape: clumps of forest amid farmland, failing to meet climate and ecosystem services targets in the process.[429] But, the opposite strategy could also produce negative consequences, if agriculture is not accommodated. These potentially competing approaches indicate the need for sound ecological and socio-economic assessment, including quantified targets for the range of restoration goals.

Implementation

Implementation challenges include: the identification and designation of degraded forest landscapes to fulfil the commitments made – in itself a major challenge, given the scale envisioned; the development of appropriate land-use definitions and designations, including within legal and other regulatory frameworks; financing sources and mechanisms, including provision for payments for performance; and, not least, the blend of ecology, emissions science and sustainable development theory and practice that will be required for land-use criteria.

Recent work on land-use options within the UNFCCC frameworks provides some starting points,[430,431] but a further valuable development would be for those have made restoration commitments to publish overviews on their plans. Alongside this there is a need to assess and synthesize the current knowledge and expertise on restoration, both within science and from the range of current (mostly small-scale) tropical projects.[432]

The emerging contributions and findings are wide-ranging: strategic overviews of large-scale objectives and potential pathways;[433] a welcome focus on forest ecology and composition, so often neglected within policy and management;[434] studies of natural recovery time-scales;[435] valuable work on the opportunity for large-scale restoration in Brazil's Atlantic Forest[436] and more broadly;[437] insights on ecosystem connectivity and catalysts;[438] analyses of carbon sequestration and storage challenges;[439] assessments of adaptation as well as mitigation potential;[440] scrutiny of the range of restoration interventions;[441] assessments of existing restoration capacity in organisational and human resources terms;[442] and opportunities for reversing defaunation.[443]

Identification of restoration interventions for climate and ecosystem purposes

There are two principal approaches for rebuilding forest carbon stocks in degraded tropical forest landscapes: natural regeneration of forests; and tree planting (afforestation, reforestation, and assisted restoration). While they are not mutually exclusive, and both will be utilised, there is a pressing need for comparative analysis of the costs, risks, and outcomes, as an essential enabling condition for the development of large-scale strategies.[444] For recovery of forest ecosystem services, the re-introduction of locally extirpated birds and mammals will in some instances be a priority, while in others there will be a requirement for the re-engineering of hydrology so as to restore water services (for example, the rewetting of drained peatland forests).

This leaves one major issue that cannot be avoided in strategy formulation: bioenergy. The IPCC's AR5 sees this as the leading transformational pathway for achieving significant emissions reductions from land-uses through the 21st century.[445] However, the underlying rationale remains contested, with the many studies seeking to bring clarity to the debate producing conflicting results.

Analyses[446] seem either to focus on the net CO_2 gain or loss at the point of combustion of solid biomass or liquid biofuels, or on the carbon and related ecological impacts of land-based bioenergy production. If either of these approaches is used as the framework for analysis without reference to the other, very different results are obtained.

Combustion analyses frequently conclude that burning for bioenergy can either be carbon neutral (regrowth of equivalent biomass equals emissions), or can produce excess sequestration (some of the regrowth continues as a carbon store rather than being burned). Land-based analyses usually conclude the opposite: carbon store losses outweigh sequestration from regrowth, leading to a carbon debt from bioenergy use that may stretch far into the future (carbon payback times); and alternative land-uses (e.g. long-term protection or recovery of a forest) outscore bioenergy in mitigation terms. A new report argues that all of these factors can be attributed to 'double counting' of carbon in bioenergy calculations – the assumption that replacement biomass is obtained from new plant growth.[447] There is a further body of research that suggests this assumption can be erroneous.

A further factor is the need to look at land capacity and availability in the context of rising demand for food and wood. If plantations are established at large scales for bioenergy, rather than for wood supply, this could both imperil food security and trigger further tropical forest degradation.

In general, economists gravitate toward the combustion approach, and ecologists to land-based assessments, while factoring in the impact of bioenergy on global wood supply seems to attract few researchers. Until assessments fully balance bioenergy, optimal climate mitigation and food and wood demand within their research frameworks, the guidance that underpins policy processes will be incomplete and potentially significantly flawed.

Conservation

Conserving tropical forests is a core goal for many organisations, and a priority within broader forest policy objectives. Conservation is one of the five pillars of REDD+; and tropical forests are central to the Convention on Biological Diversity's (CBD) biodiversity goals and mission, as embodied in the Aichi biodiversity and ecosystems targets for 2020[448] and their role in the establishment, management, and regulation of protected areas.[449]

Protected areas, biodiversity, and carbon

The congruence between biodiversity and carbon storage has been increasingly recognised,[450] especially within protected areas.[451] Additionally, a range of recent studies and reports indicate that many protected areas are effective both as bulwarks against deforestation and as a means to protect biodiversity,[452] and that deforestation and degradation increase when the designations are removed.[453,454] At the same time, protected area designations are no guarantee of success, with a number of studies indicating that problems will occur when their management fails to take account of the needs and wishes of forest communities.[455]

In aggregate, protected tropical forest areas cover 217 million hectares, store 70GtC, and protect much of the world's biodiversity.[456] However, many are insufficiently protected,[457] for a range of reasons, including inadequate finance[458] and human resources capacity, downgrading of protective designations and measures,[459] and poor relationships with communities, and weak enforcement. Projected land-use pressures and lack of coordination (at global and national levels) are likely to increase the vulnerability of protected areas,[460] with one study estimating that 20% of the carbon stored in Amazonian indigenous territories and protected areas is at risk.[461]

Challenges and opportunities

Existing protected areas only meet a modest part of the overall need for tropical forest conservation. Many critical forests are not covered by any designation affording protection, and as a result are vulnerable. This is the case for a large proportion of old growth or primary forests, over half of which are in the tropics,[462] and for secondary forests that have the potential to recover their carbon storage (via CO_2 sequestration) and biodiversity.[463, 464]

There are signs that these challenges are beginning to galvanise the conservation community to new action, particularly within the policy arena. These include the launch of IntAct (International Action for Primary Forests) in late 2014, which calls for the world's remaining primary forests to be set aside as 'no-go' or 'zero-logging' areas, and for sourcing of wood and fibres to switch from natural forests to plantations. The Statement of Principles also notes that *'current best practices and certification schemes have not reconciled industrial activity with primary forest conservation at large scales.'*[465] Another development is the mobilisation of scientific support for a stronger agenda on maintaining the ecosystems on which humanity depends.[466] On the problem of inadequate resources, it may be time to evaluate the option of including protected areas[467] within REDD+ (see **Section 7**).

At the policy level, concerns are being expressed over progress toward the Aichi targets, which contain several provisions for tropical forests. One recent study notes that while societal responses to the biodiversity crisis (such as increases in protected areas, fisheries and forest certification, and conservation agriculture) are moving in the right direction, the indicators for the underlying state of biodiversity and the pressures upon it show no significant improvement. The study goes on to suggest that the situation may worsen by 2020, relative to 2010 (including increasing ecological and water footprints and reductions in wetland habitat).[468] These issues are underlined in a recently published major update of the overall state of biodiversity.[469] A further weakness is the lack of co-ordinated action to address defaunation. While awareness of the problem has advanced significantly, much more needs to be done to further improve knowledge and advance solutions.[470]

These concerns point to a wider issue – our collective understanding of the enabling conditions for conservation success. Some studies have sought to probe the effectiveness of a range of approaches,[471] while others have argued that there is a need for more realism over the trade-offs between conservation and development goals.[472] A further perspective is that awareness of approaching tipping points may be the essential strategic ingredient, as Peter Kareiva has articulated:

> *'Modern conservation is as much about managing resource use and extraction as it is about setting aside protected areas. The biggest challenge is knowing when another mine, or another oil pad, or another hundred hectares of heavily fertilized crops is too much and thus will jeopardize both biodiversity and ecosystem services. Ecological theory reveals that thresholds and tipping points are inherent in complex nonlinear systems. But the science is lacking for anticipating where those thresholds are and how to account for cumulative impacts. The ecology of cumulative risks, resilience and thresholds, in addition to tried and true land and water protection methods, holds the key to conservation success in the Anthropocene.'*
>
> Kareiva, P., et al. 2014. *The evolving linkage between conservation science and practice at The Nature Conservancy.* Journal of Applied Ecology, Volume 51, Issue 5, pp1137–1147.[473]

A monoculture tree farm takes the place of Amazon rainforest near Macapa, Brazil, September, 2013.
Photo ©Daniel Beltrá via Catherine Edelman Gallery, Chicago

9 Sustainable forestry and the wood demand challenge

Summary points

- The role of selective logging within forestry should be re-assessed in the light of new findings on its role within degradation;
- Expanding socially inclusive and environmentally sensitive tropical plantation capacity could help to meet rising wood demand, reduce pressure on natural forests and enhance livelihoods through community plantation schemes;
- A certified degradation-free supply chain concept could be developed for plantation outputs.

The core ideas of sustainable forestry – maximum sustainable yield, rotational logging, and even-aged stands (planted forests) – have their origins in 18th century German, French, Swedish and British land economics and management, spurred by concerns over diminishing stocks of domestic timber for naval warfare and pit props. These concepts and practices were subsequently exported across the globe, including to the tropics.[474] Developments in the modern era have progressively refined many of these models, principally through the Sustainable Forest Management (SFM)[475] concept, which seeks to align forestry activities with the range of climate, forest ecosystem and sustainable development goals. Other innovations include the suite of selective logging approaches (e.g. reduced impact logging, or RIL), and the forest certification concept, developed in the 1980s.

Within global forestry policy, efforts to further SFM have been led by the UN Forum on Forests (UNFF) and the Food and Agriculture Organization (FAO). The 2007 adoption by the UN General Assembly of a non-legally binding instrument on all types of forest (the Forest Instrument) and four Global Objectives on Forests are perhaps the most significant outcomes of the last decade at the international level.[476] Other institutions and initiatives that have made notable contributions include UNEP, the CBD, and the Collaborative Partnership on Forests.[477]

The overall purpose of sustainable forestry has remained consistent throughout – the management of trees as a natural resource for the production of timber and other wood products, in ways that ensure future as well as current availability, and harmonisation with local, regional and national strategies for the sustainable development of tropical rural landscapes. The overall context, however, has changed, as forestry grapples with three inter-connected challenges: meeting rising demand for wood products; producing high wood yields per hectare so that available land for food production is optimised; and reducing wood-based emissions.

Projected growth of wood demand in the 21st century

Global wood demand is projected to rise throughout the 21st century, driven by a wide range of uses: paper and pulp, housing and other construction, fibres, furniture, veneers, fuelwood, charcoal, and decking. Estimates of the future growth in wood consumption vary considerably, with assumptions on fuelwood and other biomass energy as a key variable. One 2012 study projects global demand as potentially tripling by 2050,[478] while another more recent model[479] sees increases of between 28% (solid or sawnwood) through to 192% (recycled paper) for a range of products in 2060, relative to 2010 consumption (see **Figures 2**, **3**, and **4**).

Forestry and tropical forests

Tropical forestry practices fall into three broad classifications. These are: commercial logging (including clear-cutting), sometimes characterised as ‘industrial’; selective logging (often seen as a sub-set of SFM); and planted forests (including plantations and other afforestation and reforestation). In practice, the first two often overlap: many commercial logging operations employ the selective logging approach, although they may not be labelled in those terms. However, clear-cutting, which is still carried out in some tropical regions, would always be placed under the commercial heading in forestry analyses.

In area terms, commercial logging is still the dominant form of tropical forestry. A 2011 ITTO study notes that of forests designated for production (403 million hectares), only 30.6 million hectares are managed in ways that are consistent with sustainability. The picture is similar for forests designated for protection (358 million hectares, 22.7 million of which are assessed as being under sustainable management).[480] Logging approaches vary enormously,

Figures 2, 3 and 4: projected demand to 2060 for a range of wood products

Figure 2: Wood Consumption through 2060

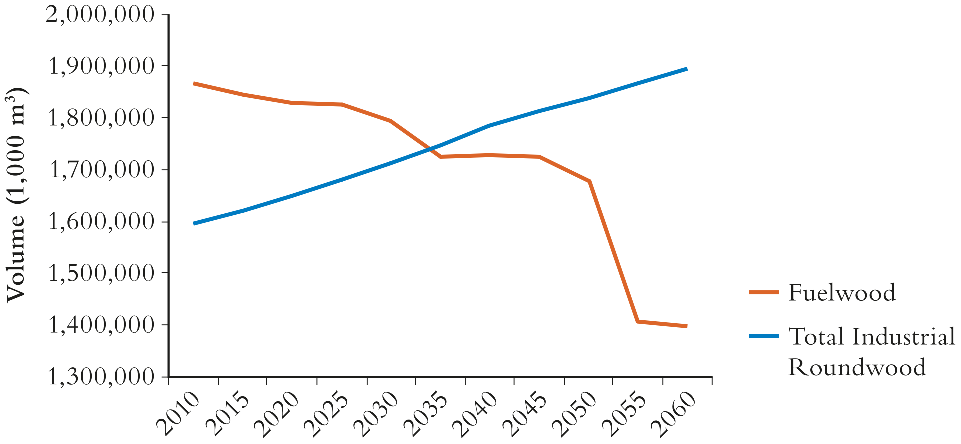


Figure 3: Solid Wood Product Consumption through 2060

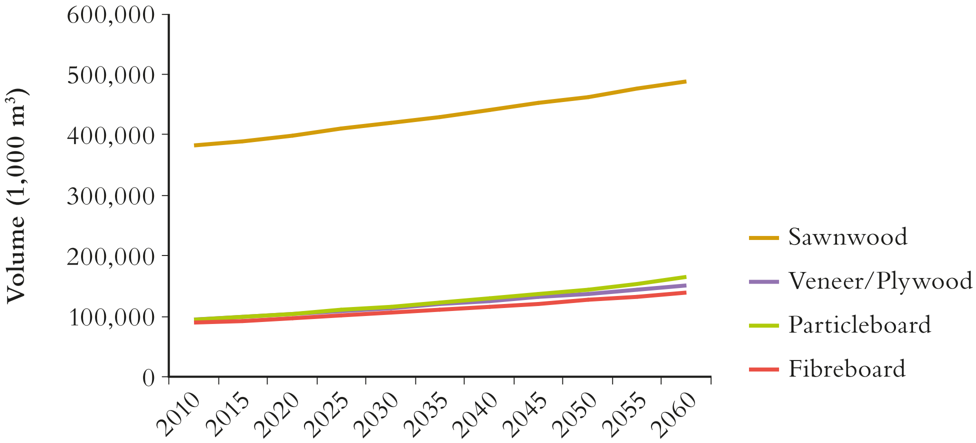
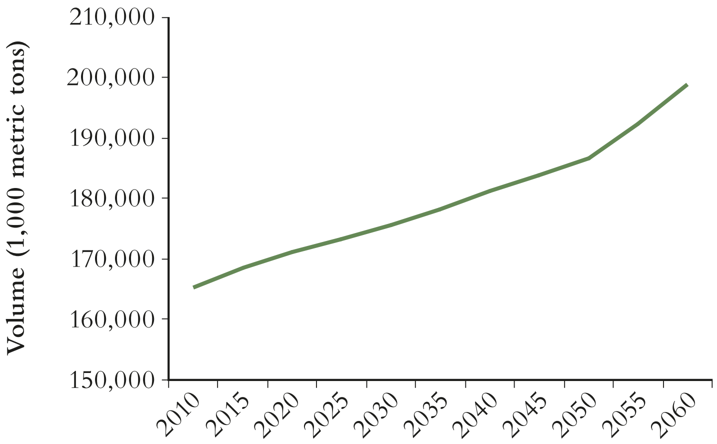


Figure 4: Woodpulp Consumption through 2060



Source: Elias, P. and D.Boucher. 2014. *Planting for the Future: How Demand for Wood Products Could Be Friendly to Tropical Forests*. Union of Concerned Scientists.

often within regions; there is no global map which distinguishes areas of clear cutting versus the various forms of selective logging, although this can be inferred to some extent from the new suite of forest monitoring tools.[481] The area of planted forests is also a relatively small component, with perhaps 70 million hectares across the tropics, within a total of 260 million hectares globally.[482]

There is broad consensus within the climate mitigation community that 'industrial' logging regimes (especially clear-cutting) that do not produce emissions reductions (relative to other extraction options) should not be admissible within REDD+. However, selective logging and plantations are in practice included within REDD+, under the *sustainable management of forests* and *enhancement of forest carbon stocks* headings, respectively,[483] though both of these forestry approaches continue to catalyse research and debate as to the nature and scale of their climate and other forest ecosystem service and outcomes.

Selective logging: an emissions reductions strategy or a driver of forest degradation?

The extent to which selective logging (and the related enabling framework, Sustainable Forest Management) is either an effective emissions reduction strategy or a driver of tropical forest degradation is contested.[484]

The mainstream forestry perspective lends support to the intervention, for two reasons: removing some trees from a forest is a contribution to emissions reductions relative to clear-cutting and other high timber extraction operations; and it is maintained that continuing forest resilience and ecological functioning are not significantly impaired by selective removals, so long as appropriate rotation (cutting) cycles are observed.

Findings from field studies broadly endorse the emissions reduction proposition; one much-cited study (of reduced impact logging in Malaysia) found that emissions were 30% lower than would have been the case relative to commercial logging.[485] And on impairment of forest functioning, some conservationists and ecologists support selective logging, arguing that it maintains vital habitats for forest-dwelling mammals and birds when compared to complete clearance.[486]

As a result, selective logging is admissible within REDD+, as noted above. From the forestry vantage point, the aim is to align as many selective logging operations as possible with climate and ecosystem goals. Sustainable Forest Management is widely seen as the enabling framework, by virtue of guidance, rules and targets for rotation cycles, species selection, efficiency in extraction and processing, least collateral damage to remaining standing trees, and a range of other good practices.

A monoculture tree farm takes the place of Amazon rainforest near Macapa, Brazil, September, 2013. Photo Daniel Beltrá via Catherine Edelman Gallery, Chicago

On the other side of the debate, while some concerns over the consequences of Sustainable Forest Management were raised in the late 1990s,[487] the body of findings that calls into question the sustainability of SFM and selective logging has largely been published since 2006 (see **Box 2**). It is unsurprising, then, that tropical forest policy has yet to fully respond.

The arguments in favour of curbing these practices are largely based on two principal contentions, although there are additional factors at play. The first maintains that the comparison with commercial logging is misleading; instead, emissions generated should be compared to those arising from no-logging regimes in forests that are fully protected. From this perspective, selective logging triggers carbon losses rather than achieving emissions reductions; as much as 40% of those from deforestation according to a recent study of two different areas in the eastern Amazon.[488]

The second is the increasing pervasiveness of selective logging. As a paper by Francis Putz notes, *'most tropical forests outside protected areas have been or will be selectively logged.'*[489] Estimates of the forest area currently or potentially impacted are difficult to ascertain, because of a lack of pan-tropical data. If Putz is correct, selective logging could eventually take place across more than 2 billion hectares (see **Table 2**). This would have a highly detrimental impact on tropical forests and their role as providers of ecosystem services, at regional, national and global scales.

Some additional factors are also causes of concern. Rotation cycles are in almost all cases too rapid to allow the renewal of tropical hardwood tree species with high carbon storage, many of which take up to a century or more to reach maturity; and poor implementation of SFM guidelines often results in greater collateral damage than was expected, highlighting the governance challenges implicit in tropical forest extractions.[490] On forest resilience, a range of negative impacts have been recorded, many of which are connected to the opening up of access to forests which often accompanies logging operations. Findings include consequent defaunation and the attendant loss of seed distributing species (see **Box 3**), and selective logging as a first step on the pathway to deforestation, where further logging cycles are conducted.[491]

Several relevant contextual points need to be made here. Firstly, selective logging is a broad term; many commercial logging practices are in fact selective (e.g. in parts of Central Africa) but not labelled as such. The rationale for selectivity includes the relatively low timber value of many tree species, and high transportation costs in remotely situated forests. Secondly, the selective logging model was not created as a response to climate change: the approach can in many ways be seen as the default mode of all forestry, with clear cutting as the anomaly (catalysed by the invention of the powered chainsaw).

These issues demonstrate the formidable nature of the sustainable logging challenge, and the depth of concern raised by recent science on the role of selective logging as a driver of degradation. One way forward would be to advance the comprehensive mapping of degradation emissions across the tropics. Donor countries could help by supporting work on national forest degradation maps within their REDD+ readiness programmes.

Beyond mapping, the principal option for reducing impacts on natural tropical forests is to meet a greater proportion of wood demand from socially inclusive, environmentally well-managed, and appropriately sited plantations established outside of natural forests (see below) which, inter alia, could contribute significantly to the reduction of emissions from forest degradation.

Great care would need to be taken to avoid negative consequences for communities, particularly where current employment and livelihoods are partially or wholly dependent on logging within secondary forests. The implication is that plantations would need to provide equal or greater benefits for communities than they can obtain from natural forest extractions; and that such a transition would need to take place equitably, democratically, and over time.

The potential of plantations as providers of wood products

The 260 million hectares of planted forests worldwide (see above) serve a range of purposes, including: combating soil erosion and desertification; protecting water catchments; supporting agroforestry and agricultural productivity more broadly (e.g. soil fertility, shade, fodder, cooler temperatures); providing sources of timber, fibres, fuelwood and charcoal.

Data on installed tropical plantation capacity is hard to ascertain: a 2012 study commissioned by the Forest Stewardship Council estimates that industrial tropical plantations are currently concentrated in Asia (17.7 million hectares) and Latin America (12.8 million hectares), within a global total of 54.3 million hectares, which is projected to expand to 91 million hectares by 2050.[492] This is likely to exclude a range of planted forests that currently provide wood supplies; another study takes the existing total planted forest area as the baseline, estimating that this could expand by a further 84.5 million hectares to 345 million hectares by 2030.[493] One report, noting the range of purposes and proliferation of approaches, defines the models as: production; industrial production; 'fastwood' monoculture; intermediate or long rotation; non-industrial; conservation; and for tree crops.[494]

The underlying question relates to current and future capacity: could the range of wood-providing plantation models meet projected demand, whilst simultaneously adhering to strict environmental and social criteria? From the productivity perspective there is a strong correlation between plantation potential and the projected increase in demand: wood to meet rising demand for pulp and paper (see **Figures 2**, **3** and **4**) can be grown very efficiently via plantation forestry. Another promising pathway is that much of the expansion could be carried out in ways that meet community needs and aspirations, including through community forest management (see **Box 6**), if the requisite levels of capital and operational investment are provided, particularly for capacity building.[495]

A further option is the potential development of a forest certification scheme that is specific to plantations. Recent critiques raise significant questions[496] but in no way invalidate the concept of certification as a valuable component of wise forestry stewardship.

Box 6: Potential of community-managed plantations to meet wood demand

Some of the most successful forest-conservation programs have been based on decentralizing control and depending on communities to make management decisions (Boucher et al. 2014). Thus it is worth evaluating the role that community management could play in the sustainable production of wood worldwide.

Community forestry enterprises have existed in Mexico for decades, providing a precedent for the participation of other countries' communities in the commercial timber sector. While there is no single model for how such enterprises work, generally they have three basic features: 1) government-granted responsibility for forest management; 2) the goal of ecologically sustainable forestry; and 3) centrality of social and economic benefits as an outcome (Charnley and Poe 2007). Such approaches provide local economic development while still meeting sustainability criteria, including forest conservation (Antinori and Bray 2005). In addition to the longstanding tradition in Mexico, community forestry is also practiced in Bolivia, India, Nepal, and the Philippines (Elias and Lininger 2010).

Another (and rapidly growing) approach to community involvement entails partnerships between forest companies and small-scale producers – known as outgrower agreements – under which local growers own and operate plantations and then sell the wood to their partner mills (Cossalter and Pye-Smith 2003). Case studies show that this process can be beneficial to both parties – the mills reduce their risk, work within policies that limit the size of landholdings, and diversify their wood sources; the tree farmers benefit from the research done by large companies, obtain the best seedlings to plant, have a guaranteed market, and spread their risk (if they are growing trees in addition to agricultural commodities) (Desmond and Race 2000). Overall, outgrower schemes usually lead to less conflict and provide enhanced local employment (Cossalter and Pye-Smith 2003).

Source: Elias, P. and D.Boucher. 2014. *Planting for the Future: How Demand for Wood Products Could Be Friendly to Tropical Forests*. Union of Concerned Scientists, p19, Box 3.

Degradation-free supply chains

Given the mounting evidence from science on emissions and associated degradation that is attributable to selective and conventional logging in the tropics, one recent report articulates two possible futures: one in which demand for wood products is met in a sustainable way through the careful use of forest plantations; and another in which business as usual for wood and paper production continues to drive forest degradation.[497,498] To increase the chances of the former outcome, a possible starting point is the development of a plantation-sourced *degradation-free* labelling concept. This could be applied to supply chains, much as 'deforestation-free' is now routinely described as the goal in the context of beef, soy and palm oil.

Next steps

Several ways forward can be foreseen to build on existing expertise: the on-going expansion of global plantation capacity could be accelerated in both temperate and tropical zones; chains of custody and certification processes could denote plantation versus natural forest sourcing; and substitutions could be sought for luxury products derived from natural tropical forest hardwood trees (which are both long-lived and store the most carbon). Such developments are not without risks; there are many instances of plantations having produced socially and ecologically damaging results. Best practices need to be followed, including recognition of community rights and livelihoods, the provision of wildlife corridors, use of local tree species where possible, and the safeguarding of water resources.

However, while the plantation expansion option holds great potential, the scale of the sustainable forestry challenge should not be under-estimated. Logging of natural forests for hardwoods is deeply embedded within land-use economics, in temperate and boreal zones as well as in the tropics. Effecting a transition that at once protects forests from degradation and ensures that the rights and livelihoods of indigenous communities are safeguarded will be a formidable undertaking, and one that requires considerable planning capability. The onus will be on plantation supporters to secure the free, prior and informed consent of communities, and to demonstrate that plantation models and approaches meet rigorous social and environmental standards.

The challenges also extend to considerations of national interest and equity. Despite the inroads made by logging operations, many countries still possess significant hardwood timber resources with high commercial value. Foregoing those revenues as a contribution to carbon and ecosystem services protection may require the development of compensation schemes, especially where communities are the beneficiaries. It could also be the case that actions are needed on the demand side, for example through the substitution of hardwood tropical timber by other materials (e.g. in construction, yachts and decking).[499]

Photo: Global Canopy Programme

10 Enabling conditions

Summary points

- Securing the right enabling conditions for wise stewardship of tropical forests is a vital but complex challenge;
- The list of required enabling conditions includes strong governance, better land use planning, land tenure reform, recognition of community rights, donor and investor confidence in forest financing schemes, effective utilisation of technology, and progress through international, regional and national bodies and initiatives;
- Each has a valid role – but so too does the management of tropical forests for protection and restoration purposes;
- As in other sectors, understanding the ingredients of success can help to guide policy, technical, and financial support into best performing models.

Introduction

The required enabling conditions for wise stewardship of tropical forests range from the mobilisation of community support and participation in management schemes through to donor and investor confidence in the durability and functionality of contractual arrangements, and the need for enabling frameworks and initiatives at international, regional and local levels.

A first grouping includes those conditions which need to be in place in advance of implementation: coherent sustainable development strategies that balance multiple objectives; land-use planning and associated laws and regulations that provide the basis for achieving forest protection; good governance and the attendant need for strong institutions; and clarification and legal recognition of the land tenure and customary and traditional rights of indigenous communities, and their free prior and informed consent with regard to forest management schemes.

A second cluster embraces considerations relating to implementation, and includes clarity over management responsibilities and objectives (as distinct from tenure);[500] and the effectiveness of the range of management models. Research findings indicate that results vary widely, with no single approach providing surety of success. An inhibiting factor in this context is the tendency to see management models (e.g. protected areas and community-managed forests) as strongly differentiated. Looking to the future, innovation may well lead to new and previously unconsidered partnerships.

A third category brings broader political and economic factors into focus. Whilst all agree that those engaged in tropical forest protection must receive fair recompense, the debate over payment sources, rules, mechanisms and channels is far from settled. Both governments and investors require confidence in the durability and functionality of contractual arrangements. This is as true for multilateral and bilateral institutions and agencies as it is for those who invest in carbon and ecosystem markets. In this context, the requirement for strong governance via national, regional and local institutions within tropical countries is a leading priority.

The role of technology as an enabler also sits under this heading. Advances in remote sensing and technology-assisted on-the-ground monitoring and assessments have been rapid over the last decade, with the result that land-use decision making can proceed on a firmer footing than previously (for example, in the identification of lands suitable for deforestation-free supply chain sourcing).

A final grouping includes the range of international, regional and national initiatives which seek to advance tropical forest protection, from the UNFCCC to the post-2015 UN Sustainable Development Goals, and the work of the Convention on Biological Diversity (CBD), The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), the Governors' Climate and Forests Task Force (GCF), The Three Basins Initiative, and many other initiatives. These pathways to better tropical forest management ultimately depend upon collective endeavour across societies, from which leaders draw their authority.

Sustainable development and land-use planning

Linking tropical forest management to sustainable development was a major outcome of the 1992 Earth Summit, as articulated in the Forest Principles.[501] These state: *'The subject of forests is related to the entire range of environmental and development issues and opportunities, including the right to socio-economic development on a sustainable basis'* and *'the guiding objective of these principles is to contribute to the management, conservation and sustainable development of forests and to provide for their multiple and complementary functions and uses.'*

The Principles, which continue to underpin global forest policy, also assert the sovereign right of States to *'exploit their own resources pursuant to their own environmental policies.'* But the text goes on to say that States *'have the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.'* The direction of travel is clear: sovereign rights should be balanced with consideration of the global public good.

The implication is that tropical forest policy can never be coercive: all rights and needs must be accommodated. Most (if not all) of the tensions and challenges around wise management are a function of the need for this balance: poor or misguided development will harm tropical forests; protection without due regard for the drive toward prosperity across the tropics will harm rights and livelihoods. Debate over this issue recently resurfaced, in the context of the 'zero-deforestation' concept, with some maintaining that more tropical deforestation is inevitable and just, while others argue that the accommodation of prosperity with forest protection remains entirely possible.[502]

One response is to explore the extent to which changes in knowledge since 1992 affect perspectives on how wise tropical forest management can be achieved, i.e. management that meets the twin goals of sustainable development and protection. In turn, this points toward the need for better and more spatially explicit land-use planning, which takes account of findings from science on biophysical priorities (including the need to protect water as well as carbon resources in tropical forests), and the collective understanding of socio-economic, political and cultural responsibilities and realities, including land, food and other rights.

There have been several recent inputs on land-use planning as it relates to Agriculture, Forestry and Other Land-Use (AFOLU), both at broad levels[503] and with respect to finance and accounting.[504] At present, most of the documentation is highly technical; more effort needs to be put into articulating the issues and options for a broader public, at global, regional and local levels. The contributions made by the New Climate Economy report and others provide valuable starting points.[505,506]

Land tenure and governance

Much work has been done over the last decade – by NGOs, international institutions, and governments – to address the challenging issues relating to land tenure, governance, institutions and participation. These efforts have led to the development of widely supported safeguards that seek to enshrine the principles of equity, respect and recognition for the range of rights, and the requirement for participation.

Within these challenges, the clarification and legal recognition of land tenure is a cornerstone for progress on the conservation, and equitable and economically rational use of forests, particularly for indigenous communities. Consequent on this are requirements for: recognition and respect for customary and traditional rights to land; adoption of the principle of free, prior and informed consent of forest communities in local and national development planning, including for infrastructure; and the development of strong and accountable local and national institutions within which local communities can participate and have an effective voice.

Without the consolidation of customary and traditional rights over time – coupled with increasing responsibility and concern by communities themselves for the sustainable custodianship of their forest resources in the face of multiple threats – efforts to protect forests are almost certainly doomed to failure.

One recent report, cited earlier, makes the case for the criticality of these enabling conditions, and also argues that the alignment of indigenous community tenure, adequate finance from donor countries, and climate mitigation objectives can achieve significant gains in tropical forest carbon and ecosystem maintenance. Examples are provided from Brazil, Liberia, Indonesia, Colombia and the DRC where such an alignment has produced success.[507] Other valuable work in this context includes the mapping of indigenous land rights in the Congo Basin.[508]

The sustainability of forest management practices adopted by forest and indigenous communities is a function of cultural traditions, in particular in indigenous reserves; the local political economy; access to markets and infrastructure; changing attitudes between generations; and access to information and support. Governments have a responsibility not only to respect such communities but also to support them in the fulfilment of their aspirations.

More broadly, all those with forest tenure or ownership – whether a local community, company[509] or other organisation which has been contracted to manage a tropical forest on behalf of a government or community – require clarity over responsibilities as well as rights. It would perhaps be a mistake to assume that tenure is a guarantor of tropical forest protection: in some cases it is, and in others it is not.[510] The critical issues of tenure rights and management obligations both point toward broader issues of governance and the necessity of strong and equitable laws for forest management.

Some progress has been made at the international level, for example through the development and adoption of safeguards within the REDD+ framework; but many challenges remain, even within key international institutions.[511] Progress rests on greater cooperation between those institutions, national forest agencies, and forest communities,[512] and greater resolve and focus on addressing the specific drivers of deforestation and degradation in particular contexts.[513]

Tropical forest management

Beyond the critical issues of tenure and rights, greater focus is also needed on different models of tropical forest management. Research findings indicate that results vary widely, with no single management regime ensuring success.

Factors that influence outcomes include: broad challenges relating to implementation;[514] the extent to which monitoring, reporting and verification requirements are workable;[515] the effectiveness of community forest management[516] and protected areas,[517] in meeting conservation and livelihood needs; the trade-offs between carbon and livelihood goals;[518] the difficulties of adapting management models to REDD, where they were originally developed for other purposes;[519] and tensions over the accommodation of conservation[520] and restoration[521] objectives within projects.

For those involved in tropical forest management, as in other contested policy areas, it can be a challenge to avoid a priori assumptions and to overcome perspectives forged in the past. Emerging evidence should advance discussions over such matters as protected areas and community forest management, two regimes which have their supporters, and their detractors, who say that too much is claimed on their behalf.[522] It is also worth bearing in mind that such models are not static, and that the appellations will in all probability develop new meanings, as tropical forest management evolves. For example, it is possible to envisage the conversion of dormant logging concessions into protected non-extractive zones, under a combination of community and private sector management, a model that would fit none of the existing labels. One factor that will remain constant, however, is effective stakeholder engagement as the foundation for success, regardless of the particular management regime.

Availability and utility of technology

Access to technology can helpfully be seen as part of enabling conditions, rather than a purely technical component of tropical forest management. For example, the development of in-country information technology resources for forest data can provide tropical nations with control over their forest knowledge, and act as a catalyst and magnet for educational advancement and expertise.[523] One advance of widespread value would be production of a high definition pan-tropical forest map, using lidar. A recent paper calculates that this could be assembled at a cost of 5% of already pledged REDD+ funding.[524] Donor countries, investors and tropical countries could combine to produce such a map, which would be likely to bring a wide range of forest-related and other benefits.

International, regional and national initiatives

The New York Declaration on Forests and the Lima Challenge

The NYDF was unveiled at the UN Climate Summit in September 2014, eliciting many positive reactions, including an assessment from the World Resources Institute, noting that the NYDF is *'the clearest statement to date by world leaders that forests can be a major force in tackling the climate challenge.'*[525] Other notable responses include a preliminary quantification of the outcomes implied by the range of pledges, indicating considerable mitigation gains (as much as 8.8GtCO_2 per year),[526] and a range of media articles highlighting the stepping up of private sector support for tropical forest action.[527]

It also attracted some critical comment, including articles declaring that private sector pledges and the commitments of countries to reduce deforestation simply repeated announcements made in 2010,[528] that the Declaration is an agreement to continue deforestation until 2030,[529] and an expression of doubt over the likelihood of action to implement the restoration pledges made by several countries.[530]

The NYDF is best seen as a package[531] incorporating specific announcements made by governments, the private sector, and civil society organisations, as well as the 10 commitments of the Declaration itself. Taken in aggregate, the NYDF addresses the imperatives comprehensively, and has the potential to be a powerful set of measures and actions.

Later in 2014, 14 developing countries (12 of which are in the tropical region) issued the Lima Challenge,[532] which calls on developed countries to join them in achieving deeper emission reductions through international collaboration. The countries highlighted their ambition and commitment to take action on their own, and that they stand ready to do more with international financial support. An interesting aspect of the Challenge is that it commits signatories to quantification of their efforts. This is a positive development that demonstrates that commitment and determination are gathering force.

The UN Sustainable Development Goals and the IPBES

Within the Millennium Development Goals, MDG7 (environmental sustainability) is widely recognised as unambitious. The UN Sustainable Development Goals (to be agreed by Member States in September 2015 as successors to the MDGs) provide an opportunity to position environmental issues more fully within the international development agenda. A SDG for the natural environment, including forests, is under discussion.[533] Such a SDG could strengthen commitments to protect tropical forests by encompassing the range of values and benefits inherent in their conservation, restoration and sustainable management.

The extent to which comprehension of the tropical forests challenge has advanced can be seen in contributions to the debate about how forests will feature in the goals, including work that blends the recently developed planetary boundaries concept with social and economic aspirations,[534] signifying moves towards integration of development and environment approaches. At the same time, some fear that the SDGs are insufficiently based on science.[535] Given that the way forward requires union rather than division,[536] efforts to reconcile these differing perspectives are likely to be worthwhile and indeed essential.

A further avenue that holds promise for tropical forests is The Inter-governmental Platform on Biodiversity and Ecosystem Services (IPBES). Established in 2012, IPBES fills a long-standing gap in the environmental governance infrastructure.[537]

Regional and national initiatives

Several important initiatives are regionally focused, aiming to advance tropical forest protection by building a strong set of relationships that reflect in situ knowledge and understanding of challenges and opportunities. These include the Governors' Climate and Forests Task Force (GCF)[538] and its partners, particularly IPAM and the Earth Innovation Institute,[539] which see state-to-state and subnational action as routes forward. Other noteworthy contributions are being made by the Three Basins Initiative, led by Guyana's former Prime Minister, Bharat Jagdeo, and the State of the Tropics project. The former is seeking to develop stronger ties and greater collaboration on forests between the countries of the three tropical basins (Amazon, Congo, South-East Asia),[540] while the latter is providing a much-needed perspective from within the tropics on the overall challenges across the region.[541]

A further necessary development has been the increase in research that focuses on national tropical forest policy and planning. While the in-country work supported by FCPF and UN-REDD is critical in this regard, other contributions are also valuable. Recently published national studies include those for Cameroon,[542] Bolivia,[543] Brazil,[544] Myanmar,[545,546] and Papua New Guinea.[547]

Collective endeavour and responsibility

Perhaps above all else, wise stewardship of tropical forests rests on broad societal support and collective endeavour. The need for strong leadership is often noted, but leaders can only act with a mandate. Science has proven beyond doubt that the carbon, water and other ecosystem services provided by tropical forests are essential for human wellbeing. This confers a collective responsibility to act, especially by countries with the resources to help the many tropical countries that cannot achieve forest protection unaided. Arguably the most pressing need of all is to communicate the message, by all means possible, that tropical forests are essential for economic prosperity.

Photo: Chris Perrett, Naturesart

Conclusions

The extent and condition of tropical forests

Tropical forests once covered 3.6 billion hectares: half of all of the world's forests. Almost a third have been lost as a result of deforestation. Of the remaining area, 46% is fragmented, 30% degraded, and only 24% (600 million hectares) is in a mature and relatively undisturbed state. Currently, c.8.5 million hectares are deforested in the tropics annually, with the rate of loss increasing by 200,000 hectares a year. These are arresting statistics, reflecting the progressive deterioration in the condition of vast areas of forest, as well as the largely irreversible clearance and conversion (mostly for agriculture) of more than 250 million hectares of tropical forest since the 1992 Rio Summit.

The current state of knowledge

Knowledge on the state of tropical forests has advanced considerably since the turn of the millennium. The data on forest extent, carbon stocks, emissions, and losses and damage from deforestation and degradation are all more accurate and nuanced than in the last century. The period since 2000 has also seen a burst of new tropical forest science, and extensive analysis of the causes of loss and degradation. These findings confirm that the less tropical forests are disturbed, the more able they are to perform the ecosystem functions on which humanity depends – including carbon sequestration and storage, and regulation of vital water services.

Conversely, much research points to the impairment of ecosystem functioning caused by disturbances such as logging, fires and roads. The implication is that policy needs to prioritise actions that greatly reduce forest fragmentation and degradation, as well as continuing and redoubling efforts to halt deforestation.

Emissions from tropical deforestation and forest degradation

Emissions from tropical deforestation (8%) and degradation (6-14%) are substantial components of overall anthropogenic carbon emissions; but up to now attention has primarily focused on the former, with much uncertainty constraining recognition of the latter. The range of estimates for emissions from degradation remains wide, but confidence in the data is steadily increasing in the light of new research. When combined, these sources account for 14-21% of the annual additions to greenhouse gas concentrations.

Current and potential tropical forest sequestration

The convention of net accounting for land-use *sources* (emissions) and *sinks* (sequestration and subsequent storage) has arguably obscured the mitigation contribution of tropical forests, by subtracting sequestration (currently 1.2–1.8GtC a year) from emissions, partly because it has been assumed that sequestration is taking place within 'naturally regenerating' secondary forests. A range of studies now indicate that, whilst secondary forests in the tropics are important sinks, so too are primary forests, which continue to absorb CO_2 – as much as half a gigatonne a year. The data highlight the importance of forest protection, as a significant amount of the sequestration can be attributed to human agency (e.g. through protected areas).

Looking forward, if efforts are redoubled to reduce carbon emissions from deforestation and degradation, and to safeguard existing tropical forest sequestration, the combined effect could be as much as 24-33% of all carbon mitigation.

Tropical forest ecosystem services

Findings from recent science underscore the fundamental importance of ecological interactions for tropical forest renewal and resilience. This is as true for recovering forests as it is for those in a mature state.

More broadly, the growing body of evidence on the inter-connectedness of tropical forest carbon, hydrology, local and regional climate regulation, ecology, and biodiversity highlights the need for a more integrated approach both within and between the science and policy communities. Recent findings indicate that future agricultural productivity in the tropics is at risk from a deforestation-induced increase in mean temperature and associated heat extremes (and from a decline in mean rainfall or rainfall frequency).

Such science illustrates the dangers of failing to take a holistic approach. Without a concerted effort, the likelihood is that policy will continue to lag well behind the science. The potential consequences for the maintenance of forest ecosystem functions - critical to human wellbeing - are severe.

Drivers of tropical forest loss and damage

The forces that cause tropical deforestation and forest degradation vary greatly through time and space, and as a function of socio-economic and political factors. There is consensus that global commodity supply chains (principally palm oil, beef, soy, pulp and paper, maize, rice, and sugar cane), are major drivers of deforestation, with oil and gas extraction, mining, roads, smallholder agriculture, fuelwood collection and charcoal production all also contributing significantly to forest loss.

Logging is widely recognised as the principal driver of forest degradation. However, until recently the consensus view was that if illegal logging were curbed, sustainable forest management practices would enable legal extractions to take place without jeopardising core carbon stocks and forest resilience. Research over the last decade calls these assumptions into question. While the prevention of illegal logging remains a priority, a range of studies find that legally permitted selective logging is also triggering significant emissions and extensive degradation across large parts of the tropics, indicating the need for a re-evaluation of forest policy at national and international levels.

Policy responses

REDD+

REDD+ is a response to the under-valuation of tropical forests, which seeks to build an economically viable framework to enable their survival and restoration. While results on the ground remain elusive, more progress has been made than is generally recognised. Perhaps the key achievements to date – in addition to the small but real successes of hundreds of pilot projects – are the development of REDD+ technical capital (the rules and guidance for social and environmental safeguards, monitoring, reporting and verification, and payments for performance, most of which are now in place) and the progress made in preparing tropical countries via REDD+ readiness capacity building. The task ahead is to take REDD+ into fully operational mode, for which several next steps can be seen:

- Investment in the development and implementation of a target-based, landscape-scale and jurisdictional approach as a key route toward delivering effective outcomes for the range of REDD+ objectives;
- Leveraging the synergies between REDD+, supply chains and restoration, which could potentially lead to a more integrated, efficient and focused approach to tropical forest management – and lower transactional costs for payments for performance;
- Assessment of the potential viability and utility of a range of mechanisms and instruments, including Jurisdictional REDD+ Bonds, public sector subsidy models (akin to Feed-In Tariffs for renewable energy) and other concessional finance approaches;
- Renewed ambition and resolve on the part of both donor and tropical countries to realise the REDD+ vision. The formidable nature of this challenge points to the need for a gear-change in outlook:
  - The doubling of finance provided by donor countries, as signalled by the New Climate Economy report;
  - The leveraging of private sector finance and engagement as a key component of the overall solution;
  - The reconsideration as to how the carbon credit market might play a role in facilitating additional support;
  - Regulatory actions by all tropical forest countries which pave the way for effective protection; and
  - In the spirit of the Lima Challenge, new contributions by tropical forest countries themselves, as they are able, whilst recognising that many will continue to rely heavily on developed countries for assistance.

At the same time, ambition and resolve are not purely a function of money. Achieving success at scale will also require a bold understanding of what it will take to reach the desired goals, in particular on the size of forest areas targeted for protection, and the volume of emissions reductions sought.

Deforestation-free supply chains and the green economy

Momentum is building toward deforestation-free supply chains for palm oil, soy and beef, with attention increasingly focusing on the implementation of corporate commitments. An immediate challenge is to manage the switch of production without triggering perverse consequences, such as the conversion of already degraded tropical forests that retain relatively high carbon or biodiversity value and have viable restoration potential. Another priority is to broaden the scope to include the many other commodities that play a part in deforestation via supply chains, and to multiply the number of companies participating.

The Bonn Challenge and tropical forest restoration

Restoration commitments announced at the UN Climate Summit in September 2014 aggregate to 350 million hectares (including the Bonn Challenge goal). By any yardstick this is an extremely positive demonstration of commitment. However, as attention shifts to implementation, two challenges stand out.

The first is to ensure a balance in the portfolio of land-uses, such that mitigation and ecosystem service objectives are not marginalised in the quest for broad based sustainable development. Quantified targets would help in this regard, as they would in the implementation of REDD+ at landscape scale. The second relates to forest recovery interventions, for which there is a pressing need to understand where the two principal interventions – natural regeneration and the suite of tree planting approaches - can most effectively be deployed.

Conservation

Growing awareness of the impacts of logging is beginning to stimulate new conservation policy thinking. For example, there were calls during the recent World Parks Congress for the world's remaining primary forests to be set aside as 'no-go' areas; and for sourcing of wood and fibres to be switched from natural forests to plantations. Such considerations are a part of the recognition that tropical forests can ultimately only be preserved if more rigour is brought to bear on land-use planning and decision-making. A parallel development might be to encourage formally designated protected areas and forests managed by indigenous communities to become REDD+ participants, in order to pave the way for a more sustainable approach to their financing.

Sustainable forestry

The strength of the case for reductions of logging in natural tropical forests points to an expansion of tropical plantation capacity as a response to rising global demand for wood-based products. This raises a number of key issues, including the extent to which existing social and environmental criteria for plantation establishment and management are fit for purpose, and the avoidance of competition for land for food production.

A next step might be to assess the potential for aligning plantations with community needs and aspirations, including through community management. Another (and complementary) approach could be to develop a *degradation-free* certification and labelling scheme for plantation outputs, mirroring plans for deforestation-free supply chains.

Enabling conditions

The enabling conditions for wise stewardship of tropical forests embrace factors ranging from the mobilisation of community support and participation in management schemes through to donor and investor confidence in the durability and functionality of contractual arrangements, and the need for effective frameworks at international, regional and local levels.

Progress has been made on many areas over the last decade, including on institution building, governance, social and environmental safeguards, participation, and land tenure reform. Although the motivation goes far beyond the need to satisfy REDD+ requirements, the advances have often been assisted by REDD readiness programmes. The challenge is to consolidate and extend progress made to date.

Internationally, there are encouraging signs of a stronger resolve to succeed in the task of protecting tropical forests. The momentum generated by the New York Declaration on Forests in 2014 – supported by governments, the private sector and civil society – should be built upon in the run up to the UNFCCC meeting in Paris at the end of 2015. But the climate agreement processes are only one of the pathways for moving the agenda forwards. Other opportunities include those provided by the agreement and implementation of the post-2015 UN Sustainable Development Goals, and the work of the CBD, The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), The Three Basins Initiative, and the Governors' Climate and Forests Task Force (GCF).

These pathways to improved tropical forest management ultimately depend upon collective endeavour across societies. Strong leadership is regularly singled out as a prerequisite for success, but leaders can only act with a mandate. Science has demonstrated beyond doubt that the carbon, water and other ecosystem services provided by tropical forests are essential for human wellbeing. This confers a shared responsibility to act, especially by countries with the resources to help the many tropical countries that cannot achieve forest protection unaided. Perhaps the most pressing need of all is to communicate the message, by all possible means, that tropical forests are essential for our survival.

Endnotes

1 See: Hansen, M.C., et al. 2013. *High-Resolution Global Maps of 21st-Century Forest Cover Change*. Science, 342, 850. This estimates the annual tropical forest area lost at 8.5 million hectares, and the annual increase in the area deforested at 200,000 hectares. This is at variance with the FAO's and Global Forest Resources Assessment 2010 which reports that: *'Around 13 million hectares of forest were converted to other uses or lost through natural causes each year in the last decade compared with 16 million hectares per year in the 1990s. Both Brazil and Indonesia, which had the highest net loss of forest in the 1990s, have significantly reduced their rate of loss.'* (pxiii). The Hansen estimate is cited in this report because it draws on advances in remote sensing and more recent data; estimated figures cited elsewhere in this report draw more heavily on this dataset than on others.

2 See a number of recent reports for valuable data and insights which complement the sources referenced throughout: WWF. 2014. *Living Planet Report 2014*; State of the Tropics. 2014. *State of the Tropics 2014 report*. James Cook University; FAO. 2014. State of the World's Forests: Enhancing the socioeconomic benefits from forests; Kusters, K. and E.Lammers 2013. *Rich Forests – The future of forested landscapes and their communities*. Both Ends; Hofsvang, E (editor). 2014. *State of the Rainforest 2014*. Rainforest Foundation Norway and GRID-Arendal; and the ongoing series of reports which comprise Seymour, F. and J.Busch. 2014. *Why Forests, Why Now? Introduction*. Center for Global Development.

3 Estimates of current global forest cover extent vary. The FAO estimate (see Global Forest Resources Assessment 2010) of 4.03 billion hectares is frequently cited, but this does not include the separate FAO category of 'other woody lands' (1.1 billion hectares). If this is included, the aggregate total of 5.13 billion hectares accords reasonably closely to the 5.34 billion hectare estimate found in Table 1.

4 FAO. 2010. *Global Forest Resources Assessment 2010*. Data on tropical deforestation vary as a function of 'gross' (actual natural forest loss) or 'net' (natural forest loss *minus* the establishment of new planted forests) calculations. FAO reported that the annual average *net* loss in the tropics was 8.9m hectares, for 2000-2010 (the gross loss is not reported). This was balanced to some extent by the establishment of c.3.7m hectares of planted forests in China, west and central Asia, the US and the EU. 8.9m minus 3.7m = the much cited 5.2m hectares net loss per annum for 2000-2010.

5 See *Global Forest Resources Assessment 2010*, Table 3: Trends in extent of forest 1990-2010.

6 Hansen, M.C., et al. 2013. *High-Resolution Global Maps of 21st-Century Forest Cover Change*. Science, 342, 850.

7 See also Kim, D-H., et al. 2015. *Accelerated Deforestation in the Humid Tropics from the 1990s to the 2000s*. Geophysical Research Letters, doi: 1002/2014GL062777. This new paper reports a 62% rise in tropical deforestation from the 1990s to the 2000s.

8 While FAO data remains the default source for tropical forest policy, other datasets that draw primarily on remote sensing (including lidar as well as optical and radar) are becoming increasingly influential and well-known. See, for example, Global Forest Watch, and Hansen, M.C., et al. 2013.

9 See *Global Forest Resources Assessment 2010*, Table 3: Trends in extent of forest 1990-2010. The 25 countries (by no means all of the countries where tropical deforestation is occurring) are (in descending order of forest area loss): Nigeria, Tanzania, Democratic Republic of Congo, Myanmar, Bolivia, Venezuela, Cameroon, Ecuador, Paraguay, Mexico, Peru, Papua New Guinea, Ethiopia, Cambodia, Angola, Honduras, Ghana, Colombia, Uganda, Malaysia, Lao PDR, Nicaragua, Madagascar, Guatemala, and Sudan. Aggregate data of this type for tropical forests should be treated with caution, in part because countries are not necessarily aligned to ecoregions: parts of Mexico and Sudan, for example are non-tropical.

10 The area data in Tables 1 and 2 are the basis of the *World of Opportunity* map developed by WRI and others for the Bonn Challenge. For background on the development of the map, see Laestadius, L., et al. 2012. *Mapping opportunities for forest landscape restoration*. Unasylva, Vol 238, Vol 62/2.

11 Margono, A., et al. 2014. *Primary forest cover loss in Indonesia over 2000–2012*. Nature Climate Change, 29th June. *'We report a spatially and temporally explicit quantification of Indonesian primary forest loss, which totalled over 6.02 Mha from 2000 to 2012 and increased on average by 47,600 ha per year. By 2012, annual primary forest loss in Indonesia was estimated to be higher than in Brazil (0.84 Mha and 0.46 Mha, respectively). Proportional loss of primary forests in wetland landforms increased and almost all clearing of primary forests occurred within degraded types, meaning logging preceded conversion processes. Loss within official forest land uses that restrict or prohibit clearing totalled 40% of all loss within national forest land.'*

12 Abood, S.A., et al. 2014. *Relative contributions of the logging, fiber, oil palm, and mining industries to forest loss in Indonesia*. Conservation Letters DOI: 10.1111/conl.12103. *'We compare the magnitudes of forest and carbon loss, and forest and carbon stocks remaining within oil palm plantation, logging, fiber plantation (pulp and paper), and coal mining concessions in Indonesia… we found that the four industries accounted for ~44.7% (~6.6 Mha) of forest loss in Kalimantan, Sumatra, Papua, Sulawesi, and Moluccas between 2000 and 2010. Fiber plantation and logging concessions accounted for the largest forest loss (~1.9Mha and ~1.8 Mha, respectively). Although the oil palm industry is often highlighted as a major driver of deforestation, it was ranked third in terms of deforestation (~1Mha), and second in terms of carbon dioxide emissions (~1,300–2,350 Mt CO_2).'*

13 Zhuravleva, I., et al. 2013. *Satellite-based primary forest degradation assessment in the Democratic Republic of the Congo, 2000–2010*. Environmental Research Letters, 8, 024034. *'From 2000 to 2010, 1.02% of primary forest cover was lost due to clearing, and almost 2% of intact primary*

forests were degraded due to alteration and fragmentation… Fragmentation and selective logging were the leading causes of intact forest degradation, accounting for 91% of IFL area change. The 10 year forest degradation rate within designated logging permit areas was 3.8 times higher compared to other primary forest areas… Given the observed forest degradation rates, we infer that the degradation of intact forests could increase up to two-fold over the next decade.'

14 Bryan, J.E., et al. 2013. *Extreme Differences in Forest Degradation in Borneo: Comparing Practices in Sarawak, Sabah, and Brunei*. PLoS ONE 8(7): e69679. doi:10.1371/journal.pone.0069679. *'We found that nearly 80% of the land surface of Sabah and Sarawak was impacted by previously undocumented, high-impact logging or clearing operations from 1990 to 2009… Overall, only 8% and 3% of land area in Sabah and Sarawak, respectively, was covered by intact forests under designated protected areas. Our assessment shows that very few forest ecosystems remain intact in Sabah or Sarawak, but that Brunei, by largely excluding industrial logging from its borders, has been comparatively successful in protecting its forests.'*

15 Finer, M., et al. 2014. *Logging Concessions Enable Illegal Logging Crisis in the Peruvian Amazon*. Nature Scientific Reports, 4 : 4719 | DOI: 10.1038/srep04719. *'We present evidence that Peru's legal logging concession system is enabling the widespread illegal logging via the regulatory documents designed to ensure sustainable logging. Analyzing official government data, we found that 68.3% of all concessions supervised by authorities were suspected of major violations.'*

16 Gutierrez-Velez, V.H., et al. 2011. *High-yield oil palm expansion spares land at the expense of forests in the Peruvian Amazon*. Environmental Research Letters, 6, 044029. *'Using satellite and field data, we assessed the area deforested by industrial-scale high-yield oil palm expansion in the Peruvian Amazon from 2000 to 2010, finding that 72% of new plantations expanded into forested areas. In a focus area in the Ucayali region, we assessed deforestation for high- and smallholder low-yield oil palm plantations… High-yield expansion minimized the total area required to achieve production but counter-intuitively at higher expense to forests than low-yield plantations. The results show that high-yield agriculture is an important but insufficient strategy to reduce pressure on forests.'*

17 Asner, G.P., et al. 2013 (a). *Elevated rates of gold mining in the Amazon revealed through high-resolution monitoring.* PNAS, Vol 110, No 46. *'We combined field surveys, airborne mapping, and high-resolution satellite imaging to assess road- and river-based gold mining in the Madre de Dios region of the Peruvian Amazon from 1999 to 2012. In this period, the geographic extent of gold mining increased 400%. The average annual rate of forest loss as a result of gold mining tripled in 2008 following the global economic recession, closely associated with increased gold prices.'*

18 Berenguer, E., et al. 2014. *A large-scale field assessment of carbon stocks in human-modified tropical forests*. Global Change Biology, 27 May, DOI: 10.1111/gcb.12627. *'by comparing our estimates of depleted carbon stocks in disturbed forests with Brazilian government assessments of the total forest area annually disturbed in the Amazon, we show that these emissions could represent up to 40% of the carbon loss from deforestation in the region. We conclude that conservation programs aiming to ensure the long-term permanence of forest carbon stocks, such as REDD+, will remain limited in their success unless they effectively avoid degradation as well as deforestation.'*

19 Gibson, L., et al. 2013. *Near-Complete Extinction of Native Small Mammal Fauna 25 Years After Forest Fragmentation*. Science, Vol 341, 27th September.

20 Corlett, R.T. 2007. *The Impact of Hunting on the Mammalian Fauna of Tropical Asian Forests*. Biotropica, 39(3): 292–303.

21 Wittemyer, G., et al. 2014. *Illegal killing for ivory drives global decline in African elephants*. PNAS, Vol 111, No 36.

22 Maisels, F., et al. 2013. *Devastating Decline of Forest Elephants in Central Africa*. PLoS One, Vol 8, Issue 3.

23 Beaune, D., et al. 2013. *Doom of the elephant-dependent trees in a Congo tropical forest*. Forest Ecology and Management 295, 109–117.

24 Dirzo, R., et al. 2014. *Defaunation in the Anthropocene*. Science, Vol 345, Issue 6195. *'We live amid a global wave of anthropogenically driven biodiversity loss: species and population extirpations and, critically, declines in local species abundance. Particularly, human impacts on animal biodiversity are an under-recognized form of global environmental change. Among terrestrial vertebrates, 322 species have become extinct since 1500, and populations of the remaining species show 25% average decline in abundance. Invertebrate patterns are equally dire: 67% of monitored populations show 45% mean abundance decline. Such animal declines will cascade onto ecosystem functioning and human well-being.'*

25 See, for example: Kim, D-H., et al. 2014. *Global, Landsat-based forest-cover change from 1990 to 2000*. Remote Sensing of Environment, DOI: 10.1016/j.rse.2014.08.017; and Asner, G.P., et al. 2010 (a). *High-resolution forest carbon stocks and emissions in the Amazon*. PNAS, Vol 107, No 38.

26 See Asner, G.P., et al. 2013 (b). *High-fidelity national carbon mapping for resource management and REDD+*. Carbon Balance and Management, 8:7; Cutler, M.E.J., et al. 2012. *Estimating tropical forest biomass with a combination of SAR image texture and Landsat TM data: An assessment of predictions between regions*. ISPRS Journal of Photogrammetry and Remote Sensing, 70, 66–77; Sarker, L.R. and J.E.Nichol. 2011. *Improved forest biomass estimates using ALOS AVNIR-2 texture indices*. Remote Sensing of Environment, 115, 968–977; and Andersen, H-E., et al. 2013. *Monitoring selective logging in western Amazonia with repeat lidar flights*. Remote Sensing of Environment, Vol 151, pp157-165.

27 Mitchard, E.T.A., et al. 2014. *Markedly divergent estimates of Amazon forest carbon density from ground plots and satellites*. Global Ecology and Biogeography. Vol 23, Issue 8, pp935-946. *'The differences between plots and RS [remote sensing] maps far exceed the uncertainties given in these studies, with whole regions over- or under-estimated by > 25%, whereas regional uncertainties for the maps were reported to be < 5%.'*

28 Sizer, N., et al. 2014. *Counting trees to save the woods: using big data to map deforestation*. Guardian Professional, 2nd October.

29 Asner, G.P., et al. 2014. *Targeted carbon conservation at national scales with high-resolution monitoring.* PNAS, 10th November.

30 See http://www.plos.org/about/plos/history/

31 See http://www.sciencedaily.com/

32 See http://www.globalforestwatch.org/. GFW employs a spatial resolution of 30 metres, a huge advance on prior (publicly available) mapping.

33 Harris, N., et al. 2014. *World Lost 8 Percent of its Remaining Pristine Forests Since 2000*. Global Forest Watch, 4th September. *'Almost 95 percent of IFLs are concentrated within tropical and boreal regions. Just three countries – Canada, Russia and Brazil – contain 65 percent of the world's remaining IFLs. These countries also account for more than half of all IFL degradation, although the drivers in each country are vastly different, from human-caused fires and logging in Russia, to road construction and conversion to agriculture in Brazil.'*

34 The Forest Carbon Partnership Facility (FCPF) and the UN-REDD Programme – the two initiatives charged with responsibility for assisting tropical countries to prepare for REDD+ – have 44 and 56 partner countries, respectively.

35 Hance, J. 2014. *Just how bad is the logging crisis in Myanmar? 72 percent of exports illegal*. Mongabay, 26th March.

36 Oluka, B.H. 2014. *Running to reforest: communities, NGOs work to save Ugandan reserve in the midst of massive deforestation*. Mongabay, 21st August.

37 Zvomuya, F. 2014. *Rebuilding Kissama: war-torn Angola's only national park affected by deforestation, but refaunation gives hope*. Mongabay, 24th July.

38 Panela, S. 2014. *The Philippines: where 'megadiversity' meets mega deforestation*. Mongabay, 31st July.

39 Watsa, M.E. 2014. *A paradise being lost: Peru's most important forests felled for timber, crops, roads, mining*. Mongabay, 12th August.

40 MacDonald, C. 2014. *Green Going Gone: The Tragic Deforestation of the Chaco*. Rolling Stone, 28th July.

41 Watsa, M.E. 2014. *'Natural Reserves' no more: illegal colonists deforest huge portions of Nicaraguan protected areas*. Mongabay, 13th August.

42 Stiles, D. 2014. *Ndoki Forest, charmed or cursed? Conservationists admit sustainable logging wilting in naïve chimp habitat*. Mongabay, 1st August.

43 See: Wolosin, M. 2014. *Quantifying the Benefits of the New York Declaration on Forests*. Climate Advisers, 24th September; Lang, C. 2014. *The New York Declaration on Forests: An agreement to continue deforestation until 2030*. REDD Monitor, 26th September; and Morgan, J., et al. 2014. *Analyzing Outcomes from the U.N. Climate Summit*. World Resources Institute. 23rd September; Stevens, C., et al. 2014. *Securing Rights, Combating Climate Change: How Strengthening Community Forest Rights Mitigates Climate Change*. World Resources Institute and commentary on the report by: Zwick, S. 2014. *Study Says Carbon Finance Saves Forests By Promoting Indigenous Rights*. Ecosystem Marketplace, 6th August; and Busch, J. 2014. *Indigenous Peoples Prevent Deforestation. What About Other Local Communities?* Center for Global Development, 12th August; and The Economist. 2014. *Tropical forests – A clearing in the trees. New ideas on what speeds up deforestation and what slows it down*. 23rd August, and the leader article in the same issue, *Seeing the wood. Saving trees is one of the best ways of saving the environment*; and Ellis, J.J. and P.Ellis. 2014. *Trees offer a way to delay the consequences of climate change*. Washington Post, 19th September.

44 Lawson, S., et al. 2014 (a). *Consumer Goods and Deforestation: An Analysis of the Extent and Nature of Illegality in Forest Conversion for Agriculture and Timber Plantations*. Forest Trends.

45 Assumes 220 tons of carbon (807 tons of CO_2) for a hectare. See also, Ziegler, A.D., et al. 2012. *Carbon outcomes of major land-cover transitions in SE Asia: great uncertainties and REDD+ policy implications*. Global Change Biology, 18, 3087–3099.

46 On deforestation losses, see Hansen, M.C., et al. 2013. This estimates gross tropical forest loss as 1.1m km^2 (110m hectares) for 2000-2012, an average of 8.5m hectares per year.

47 See Grace, J., et al. 2014. *Perturbations in the carbon budget of the tropics*. Global Change Biology, doi: 10.1111/gcb.12600., p4: *'Ziegler et al. (2012) reported the range of aboveground carbon per area of tropical ecosystems to vary from a few tonnes per hectare to over 400 Mg [tons] C ha^{-1}.'*

48 Emissions from tropical deforestation have been intensely studied in recent years, resulting in a plethora of peer-reviewed papers and syntheses. Sources for the data given here are: Harris, N.L., et al. 2012. *Baseline Map of Carbon Emissions from Deforestation in Tropical Regions*. Science, 336, 1573-1576 (0.8GtC); Grace, J., et al. 2014; and Houghton, R.A. 2013 (a). *The emissions of carbon from deforestation and degradation in the tropics: past trends and future potential*. Carbon Management (2013) 4(5), 539-546).

Other much-cited sources (some of which report lower or higher emissions than the estimates given here) include: Van der Werf, G.R., et al. 2009. *CO_2 emissions from forest loss*. Nature GeoScience, Vol 2 (1.2GtC for deforestation and degradation); Baccini, A., et al. 2012. *Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps*. Nature Climate Change. 29 January (1.1GtC or 2.2GtC depending on interpretation – see Harris, N., et al. 2012. *Progress Toward a Consensus on Carbon Emissions from Deforestation*. Winrock International for a reconciliation between the Harris et al Science paper and Baccini); Pan, Y., et al. 2011. *A Large and Persistent Carbon Sink the World's Forests*. Science Express, 14 July (2.9GtC).

Both Grace (2014) and Houghton (2013(a) provide helpful commentary on the range of estimates (for degradation as well as deforestation) including analyses of differences. Other valuable resources include: Saatchi, S.S. 2011. *Benchmark map of forest carbon stocks in tropical regions across three continents*. PNAS, Vol 108, No 24; Hansen, M.C., et al. 2013; Ciais,P., et al. IPCC. 2013 [AR5]. *Carbon and Other Biogeochemical Cycles*. In: *Climate Change 2013: the Physical Science Basis, Chapter 6. Contribution of Working Group 1 to the Fifth Assessment Report of the IPCC* [Stocker, T.F., et al, eds]. Cambridge University Press, pp489-490; and Smith, P., et al. 2014 [AR5]. *Agriculture, Forestry and Other Land Use (AFOLU). Climate Change 2014: Mitigation of Climate Change. Chapter 11. Contribution of Working Group III to the Fifth Assessment Report of the IPCC* [Edenhofer, O., et al, eds]. Cambridge University Press, pp825-829. Both volumes in IPCC AR5 provide detailed analysis of the most of the papers and models cited here, plus many others. See also IPCC. 2014. *Climate Change 2014: Synthesis Report*.

49 Data from Hansen, M.C., et al. 2013. Note that FAO estimate annual deforestation losses at 13 million hectares (see *FRA 2010*).

50 Boucher, D. et al. 2014. *Deforestation Success Stories – Tropical Nations Where Forest Protection and Reforestation Policies Have Worked*. Union of Concerned Scientists.

51 Nepstad, D., et al. 2014. *Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains*. Science, 6 June, Vol 344 Issue 6188. Brazil's deforestation rate has, however, increased in the last two years. See BBC News. 2014. *Figures confirm Amazon rainforest destruction rate*. 24th September. This reports that deforestation jumped 29% in 2013.

52 See Hansen, M.C., et al. 2013. *'Brazil's well-documented reduction in deforestation was offset by increasing forest loss in Indonesia, Malaysia, Paraguay, Bolivia, Zambia, Angola, and elsewhere.'* The paper also provides a listing of countries ranked by the highest percentage forest loss. All of the top 6 are in the tropics: Malaysia (14.4%); Paraguay (9.6%); Indonesia (8.4%); Guatemala (8.2%); Cambodia (7.1%); and Nicaragua (6.8%). See also Mongabay.com. 2014. *NASA: Forest loss leaps in Bolivia, Mekong region*. 8th August. This reports NASA-derived observations on sharply increased deforestation (in the second quarter of 2014) in Bolivia, Laos, Cambodia, Vietnam the Philippines, the Central Kalimantan region of Indonesia, and Peru.

53 References are as follows: Harris, N., et al. 2012 (0.6GtC for degradation, 1.4GtC for deforestation and degradation); Houghton, R.A. 2013 (a) (1.32GtC for degradation, 2.28GtC for deforestation and degradation); Pan, Y., et al. 2011 (2.9GtC – this does not fully distinguish between deforestation and degradation). Baccini, A., et al. 2012 reports a total of 2.22GtC for all emissions. Grace, J., et al. 2014 reports 1.1GtC from degradation. This includes 0.54GtC for emissions from tropical peatland forests, an element of degradation that has been excluded from a number of studies.

54 See, for example, Tipper, R., et al. 2014. *The ICF Hectares Indicator: A review and suggested improvements to the indicator methodology*. Ecometrica. This valuable review of methodological issues highlights the limitations of satellite data in tropical forest degradation mapping.

55 See Grace, J., et al. 2014, pp5-6.

56 See Houghton, R.A. 2013 (a) for reflections on the challenges for policy-makers, noting (with reference to the different results from Harris and Baccini) that *'if state-of-the-art estimates of carbon emissions from tropical deforestation vary by a factor of three, there is little hope for the implementation of REDD+.'*

57 Berenguer, E., et al. 2014.

58 Huang, M. and G.P.Asner. 2010 (b). *Long-term carbon loss and recovery following selective logging in Amazon forests*. Global Biogeochemical Cycles, Vol 24, GB3028.

59 Bryan, J.E., et al. 2013.

60 Pearson, T.R.H., et al. 2014. *Carbon emissions from tropical forest degradation caused by logging*. Environmental Research Letters, 9.

61 See Houghton, R.A., et al. 2012. *Carbon emissions from land use and land-cover change*. PP 5134 – 5137. http://www.biogeosciences.net/9/5125/2012/bg-9-5125-2012.pdf

62 Hansen, M.C., et al. 2013.

63 Lidar is a remote sensing technology that measures distance by illuminating a target with a laser and analysing the reflected light.

64 Asner, G.P., et al. 2013 (b).

65 Pan et al estimate current tropical forest gross uptake (sequestration) at 1.6GtC, a range that Grace and Houghton also reference, alongside many other studies.

66 Hansen, J, et al. 2013. *Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*. PloS One, Vol 8, Issue 12. *'Of course fossil fuel emissions will not suddenly terminate. Nevertheless, it is not impossible to return CO_2 to 350 ppm this century. Reforestation and increase of soil carbon can help draw down atmospheric CO_2.'*

67 Lovejoy, T.E. 2014. *A "Natural" Proposal for Addressing Climate Change*. Ethics and International Affairs, Issue 28:3. Includes a recommendation for the rehabilitation of mangrove forests within its prescription. The estimate of a 50ppm reduction is equivalent to 107GtC.

68 IPCC provides some guidance on the sequestration question within Smith, P., et al. 2014 [AR5], p869: *'forestry mitigation options – including reduced deforestation, forest management, afforestation, and agro-forestry – are estimated to contribute 0.2 – 13.8 $GtCO_2$ / yr of economically viable abatement in 2030 at carbon prices up to 100 USD / tCO_2eq.'* See also p861, for analysis of land-based mitigation in the 'transformational pathway' context, which sees bioenergy as the dominant intervention: *'Cumulatively, over the century, bioenergy was the dominant strategy, followed by forestry, and then agriculture. Bioenergy cumulatively generated approximately 5 to 52 $GtCO_2eq$ and 113 to 749 $GtCO_2eq$ mitigation by 2050 and 2100, respectively. In total, land-related strategies contributed 20 to 60 % of total cumulative abatement to 2030, 15 to 70 % to 2050, and 15 to 40 % to 2100.'*

69 2 tons of carbon per hectare per year is the value employed in Houghton, R.A. 2013 (a).

70 See http://www.wri.org/resources/maps/global-map-forest-landscape-restoration-opportunities for an overview of the restoration opportunity at the global level. This estimates the potential for restoration to 'closed forests' at 500 million hectares.

71 The extent to which this would be additional sequestration is unknown, because some of the current gross uptake is already taking place on degraded tropical forests.

72 The full calculation is 2 tons of carbon * 781 million hectares * 3.67 [conversion to CO_2] * 35 years, divided by 7.81 [conversion to parts per million].

73 Houghton, R.A. 2013 (a). Identifies the potential to achieve gross uptake of 1-3GtC per year, plus a further 2GtC of emissions saving through the avoidance of deforestation and degradation.

74 A comparison of data for deforestation and degradation between Table 3 and Table 6 appears to indicate percentage differences. For example, in Table 3, deforestation of 0.9GtC (John Grace *et al*) = 8.49%, whereas in Table 6 the same data = 7.22%. This is because the two Tables are providing different perspectives. Table 3 is expressing emissions as a percentage of carbon mitigation, exclusive of sequestration; Table 6 includes sequestration within the mitigation estimate. In general, tropical forest accounting does not include sequestration within mitigation estimates. However, this report takes the view that it should be included, as a proportion of sequestration is occurring as a result of human agency (e.g. through protected areas). Inclusion within estimates will help to raise awareness of the need to safeguard existing sequestration, as well as reduce emissions.

75 See Schimel, D., et al. 2014. *Effect of increasing CO_2 on the terrestrial carbon cycle*. PNAS, 29th December. This provides a valuable overview of current knowledge on terrestrial fluxes, concluding that *'The future tropical balance of deforestation and climate sources and regrowth and CO_2 sinks will only remain a robust feature of the global carbon cycle if the vast tropical forests are protected from destruction.'*

76 See: The Global Commission on the Economy and Climate. 2014. *Better Growth, Better Climate: The New Climate Economy Report*. See p17, Box 5, Chapter 3: Land Use; and Wolosin, M. 2014.

77 The Global Commission on the Economy and Climate. 2014. See p17, Box 5, Chapter 3: Land Use.

78 Goodman, R.C. and M.Herold. 2014. *Why maintaining tropical forests is essential and urgent for a stable climate*. Center for Global Development, Climate and Forest Paper Series, No 11.

79 Busch, J. and J.Engelmann. 2014. *Tropical Forests Offer up to 24–30 Percent of Potential Climate Mitigation*. Center for Global Development, 14th November.

80 In the longer-term, space-based observations may enable comprehensive measurement of terrestrial releases, but the first satellite dedicated to this purpose was only launched in the summer of 2014. See Amos, J. 2014. *Nasa launches carbon dioxide observer*. BBC News.

81 See Ciais, P., et al. 2013 [AR5]. pp489-490: *'we adopt an uncertainty of ±0.8 PgC [GtC] yr–1 as representative of 90% uncertainty intervals.'* The level of uncertainty is high: the average net emissions figure from land use change is within a range from 0.1 – 1.7GtC, and is accorded 'medium confidence'. By contrast, the data for emissions from fossil fuel emission and cement production for the same period are seen in a narrower range, in statistical terms (7.6 – 9GtC, average 8.3GtC), and are flagged with *'high confidence.'*

82 One specific area of uncertainty (sometimes neglected in forest mitigation studies) relates to carbon storage in soils. The likelihood is that current models are providing under-estimates, because most field research only analyses the top one metre.

83 Biogeochemical exchanges involving forests include releases of gases and volatile organic compounds (e.g. CO_2, methane, nitrogen oxides, ozone, fungal spores, pollen, bacteria), and water and soil-based nutrient dynamics (e.g. precipitation, evaporation, transpiration, potassium, calcium and phosphorus cycling and recycling). Forests are at once responding to inputs and acting as agents of change through their responses: absorbing and emitting gases and compounds, receiving rainfall and generating it through evaporation and transpiration, converting CO_2 to carbon and nitrogen oxides to nitrogen, and vice versa.

84 For example, some land-sourced emissions reach the atmosphere via the oceans, through fluvial flows, and from mangrove forests. See Grace, J., et al. 2014. pp3-4.

85 See Smith P., et al. 2014 [AR5], p825-829 for a review of greenhouse gas fluxes from forestry and other land uses. On gross accounting, see Ciais, P., et al. 2013 [AR5] p50, which attributes 3GtC per year to 'gross' [largely tropical] deforestation, balanced to a large extent by 2GtC of sequestration from *'forest regrowth in some regions, mainly abandoned agricultural land.'* For an overview of accounting challenges on anthropogenic/non-anthropogenic land-use issues, see Houghton, R.A. 2013 (b) *Keeping management effects separate from environmental effects in terrestrial carbon accounting*. 2013. Global Change Biology 19, 2609-2612.

86 For an excellent graphical overview of the global carbon cycle, see *Figure 1: Changes in the primary stocks of the global carbon cycle*, in: Mackey, B., et al. 2013. *Untangling the confusion around land carbon science and climate change mitigation policy.* Nature Climate Change, Vol 3, 29th May.

87 See Smith, P., et al. 2014 [AR5], p819. *'Estimating and reporting the anthropogenic component of gross and net AFOLU GHG fluxes to the atmosphere, globally, regionally, and at country level, is difficult compared to other sectors. First, it is not always possible to separate anthropogenic and natural GHG fluxes from land. Second, the input data necessary to estimate GHG emissions globally and regionally, often based on country-level statistics or on remote-sensing information, are very uncertain. Third, methods for estimating GHG emissions use a range of approaches, from simple default methodologies such as those specified in the IPCC GHG Guidelines (IPCC, 2006), to more complex estimates based on terrestrial carbon cycle modelling and / or remote sensing information.'*

88 See Smith, P., et al. 2014 [AR5], p816. *'emissions from the AFOLU sector have remained similar but the share of anthropogenic emissions has decreased to 24% (in 2010), largely due to increases in emissions in the energy sector.'* See also [same page]: *'Annual GHG emissions (mainly CH4 and N2O) from agricultural production in 2000–2010 were estimated at 5.0–5.8 $GtCO_2eq/yr$* ['comprising about 10-12% of global anthropogenic emissions'] *while annual GHG flux from land use and land-use change activities accounted for approximately 4.3–5.5 $GtCO_2eq/yr$.'* ['or, about 9-11% of total anthropogenic greenhouse gas emissions.']. The statements quoted in square brackets are from the earlier published draft of Smith, P., et al, but are omitted in the final version (the data referred to are the same). The 9-11% range matches the estimate for tropical deforestation, implying that all other land-use emissions reach zero when sequestration is accounted for.

89 See Smith, P., et al. 2014 [AR5], p826. *'The bookkeeping model method… uses regional biomass, growth and decay rates from the inventory literature that are not varied to account for changes in climate or CO_2. It includes forest management associated with shifting cultivation in tropical forest regions as well as global wood harvest and regrowth cycles. The primary source of data for the most recent decades is FAO forest area and wood harvest (FAO, 2010). FAOSTAT (2013) uses the default IPCC methodologies to compute stock-difference to estimate emissions and sinks from forest management, carbon loss associated with forest conversion to other land uses as a proxy for emissions from deforestation, GFED4 data on burned area to estimate emissions from peat fires, and spatial analyses to determine emissions from drained organic soils (IPCC, 2007b). The other models… are process-based terrestrial ecosystem models that simulate changing plant biomass and carbon fluxes, and include climate and CO_2 effects, with a few now including the nitrogen cycle… Inclusion of the nitrogen cycle results in much higher modelled net emissions in the ISAM model… as N limitation due to harvest removals limits forest regrowth rates, particularly in temperate and boreal forests. Change in land cover in the process models is from the HYDE dataset… based on FAO cropland and pasture area change data. Only some process models include forest management in terms of shifting cultivation (VISIT) or wood harvest and forest degradation (ISAM); none account for emissions from peatlands.'*

90 Ciais, P., et al. 2013 [AR5] p50.

91 Smith, P., et al. 2014 [AR5], p816.

92 Ciais, P., et al. 2013 [AR5]. p.50: *'Land use change emissions between 2002 and 2011 are dominated by tropical deforestation, and are estimated at 0.9 [0.1 to 1.7] PgC yr–1 (medium confidence), with possibly a small decrease from the 1990s due to lower reported forest loss during this decade.'*

93 IPCC. 2001. Climate Change 2001: The Scientific Basis. p7: *'About three-quarters of the anthropogenic emissions of CO_2 to the atmosphere during the past 20 years is due to fossil fuel burning. The rest is predominantly due to land-use change, especially deforestation.'* See also p41, http://www.grida.no/climate/ipcc_tar/wg1/pdf/WG1_TAR-FRONT.pdf

94 Smith, P., et al. 2014 [AR5], p816.

95 Another example of the dangers of mismatching of data can be seen in papers by Tubiello et al, (Tubiello, F.N., et al. 2015. *The Contribution of Agriculture, Forestry and other Land Use activities to Global Warming, 1990-2012.* Global Change Biology, doi: 10.1111/gcb.12865) and De Richter and Houghton (DeB Richter, D. and R.A. Houghton. 2011. *Gross CO_2 fluxes from land-use change: implications for reducing global emissions and increasing sinks.* Carbon Management, 2(1), 41–47). Tubiello et al estimate greenhouse gas emissions from agriculture at 4.8$GtCO_2$e for 2012. This appears a much lower figure than the 4.3GtC (for 2000-2005) provided in De Richter and Houghton. But the former refers to GHG emissions from agriculture, and the latter to carbon emissions for land-use change.

96 See the Carbon Dioxide Information Analysis Center, http://cdiac.ornl.gov/ftp/ndp030/global.1751_2010.ems

97 Le Quere, C., et al. 2013. *Global Carbon Budget 2013.* Earth Syst. Sci. Data Discuss., 6, 689–760. *'For the last decade available (2003–2012), EFF [carbon emissions] was 8.6±0.4 GtC yr−1… For year 2012 alone, EFF grew to 9.7±0.5GtCyr−1, 2.2% above 2011, reflecting a continued trend in these emissions.'*

98 The use of *gross* is fraught with difficulty. If humans did not exist, some deforestation would still occur, releasing CO_2 in the process. One solution would be to create a map that distinguished between natural versus anthropogenic forest loss. However, some apparently natural drivers (e.g. landslides) are themselves the product of prior human-induced deforestation in adjacent lands, or are the outcome from degradation within a forest. Additionally, individual trees die within forests that renew themselves – also releasing CO_2. But, in tropical forest climate and carbon science, *gross* often refers to emissions that are directly attributable to human actions (e.g. observed conversion of a forest for soybean cultivation).

99 For example, a large-scale natural disaster event in a particular country might trigger high emissions that render the achievement of an emissions reduction target impossible (if those emissions are treated as anthropogenic).

100 Saatchi, S. 2011. *Benchmark map of forest carbon stocks in tropical regions across three continents.* PNAS, Vol 108, No 24.

101 Meinshausen, M., et al. 2009. *Greenhouse-gas emission targets for limiting global warming to 2°C.* Nature, Vol 458, 30th April.

102 Diffenbaugh, N.S. and M.Scherer. 2011. *Observational and model evidence of global emergence of permanent, unprecedented heat in the 20th and 21st centuries.* Climatic Change 107:615-624. *'In contrast to the common perception that high-latitude areas face the most accelerated response to global warming, our results demonstrate that in fact tropical areas exhibit the most immediate and robust emergence of unprecedented heat, with many tropical areas exhibiting a 50% likelihood of permanently moving into a novel seasonal heat regime in the next two decades.'*

103 IPCC, 2012: Summary for Policymakers. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., et al, eds]. The report warns that substantial warming in temperature extremes, heavy precipitation/proportion of total rainfall from heavy falls over many areas of the globe, and increases of average tropical cyclone maximum wind speed are likely, amongst other guidance on extreme weather/climate impacts through the 21st century.

104 See: Settele, J., et al. 2014 [AR5]. *Terrestrial and inland water systems.* In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., et al, eds]. Cambridge University Press. This notes (p276): *'Climate change alone is not projected to lead to abrupt widespread loss of forest*

cover in the Amazon during this century a (medium confidence), but a projected increase in severe drought episodes, together with land use change and forest fire, would cause much of the Amazon forest to transform to less dense, drought- and fire-adapted ecosystems, and in doing so put a large stock of biodiversity at elevated risk, while decreasing net carbon uptake from the atmosphere (low confidence). Large reductions in deforestation, as well as wider application of effective wildfire management, lower the risk of abrupt change in the Amazon, as well as the impacts of that change (medium confidence).'

105 See: Gibson, L., et al. 2011. *Primary forests are irreplaceable for sustaining tropical biodiversity.* Nature, Vol 478, 378–381; Barlow, J., et al. 2007. *Quantifying the biodiversity value of tropical primary, secondary, and plantation forests.* PNAS, Vol 104, No 47; Bauer, S. and B.J.Hoye. 2014. *Migratory Animals Couple Biodiversity and Ecosystem Functioning Worldwide.* Science, Vol 344, 4th April; and Pimm, S., et al. 2014. *The biodiversity of species and their rates of extinction, distribution, and protection.* Science, Vol 344, Issue 6187.

106 A trophic cascade is an ecological phenomenon triggered by the addition or removal of top predators and involving reciprocal changes in the relative populations of predator and prey through a food chain, which often results in dramatic changes in ecosystem structure and nutrient cycling. For example, an increase (or decrease) in carnivores will ripple down the food chain, impacting populations of herbivores and primary producers such as plants and phytoplankton.

107 Ripple, W.J., et al. 2014. *Status and Ecological Effects of the World's Largest Carnivores.* Science, Vol 343, 10th January.

108 Estes, J.A., et al. 2011. *Trophic Downgrading of Planet Earth.* Science, Vol 333, 15 July.

109 Parr, C.L., et al. 2014. *Tropical grassy biomes: misunderstood, neglected, and under threat.* Trends in Ecology and Evolution, Vol 29, Issue 4, pp205-213.

110 Barnosky, A.D., et al. 2012. *Approaching a state shift in Earth's biosphere.* Nature, Vol 486, 7th June. See also Barnosky, A.D., et al. 2014. *Scientific Consensus on maintaining humanity's life support systems in the 21st century: information for policy makers.*

111 See: Rockstrom, J., et al. 2009. *Planetary Boundaries: Exploring the Safe Operating Space for Humanity.* Ecology and Society 14(2): 32; and Steffen, W., et al. 2015. *Planetary boundaries: guiding human development on a changing planet.* Science, 15th January.

112 Tilman, D. 2012. *Biodiversity & Environmental Sustainability amid Human Domination of Global Ecosystems.* Daedalus, 141 (3).

113 See, for example, Estes, 2011, which notes that while the theory of 'trophic cascades' (the impacts of animals on their prey, downward through food webs) has been around for more than a century, most of the key supporting empirical evidence has been published since 2000. The paper also articulates the wider implications: *'the loss of apex consumers [carnivores and herbivores] is arguably humankind's most pervasive influence on the natural world… Recent research suggests that the disappearance of these animals reverberates further than previously anticipated, with far-reaching effects on processes as diverse as the dynamics of disease; fire; carbon sequestration; invasive species; and biogeochemical exchanges among Earth's soil, water, and atmosphere… These findings suggest that trophic downgrading acts additively and synergistically with other anthropogenic impacts on nature, such as climate and land use change, habitat loss, and pollution.'*

114 For an excellent introductory textbook, see Ghazoul, J. and D.Sheil. 2010. *Tropical Rain Forest Ecology, Diversity, and Conservation.* Oxford University Press.

115 Terborgh, J., et al. 1990. *Structure and organization of an Amazonian forest bird community.* Ecological Monographs 60, 213-238.

116 For germination, tropical forests rely on three strategies: delayed germination (spreading risk over time); dormancy (many seeds survive for up to a year in forest floor litter); and built-in redundancy (up to 15,000 seeds per metre have been recorded in secondary forests, (see Garwood, N.C. 1989. *Tropical soil seed banks: a review.* In: *Ecology of Soil Seed Banks.* Leck, M.A., et al. Academic Press), and up to 3,000 in mature forests (see Dupuy, J.M. and R.Chazdon. 1998. *Long-term effects of forest regrowth and selective logging on the seed bank of tropical forests in NE Costa Rica.* Biotropica 30, 223-237), which at once provides a food source for seed-eating animals, and ongoing tree renewal. These germination strategies make sense in the context of undisturbed humid tropical forests because fires from natural causes are virtually unknown, except after severe droughts.

117 See: Flongnzossie, E.F., et al. 2014. *Above-ground carbon assessment in the Kom-Mengamé forest conservation complex, South Cameroon: Exploring the potential of managing forests for biodiversity and carbon.* Natural Resources Forum, Vol 38, pp220-232.

118 Slik, J.W.F., et al. 2013. *Large trees drive forest aboveground biomass variation in moist lowland forests across the tropics.* Global Ecology and Biogeography, Vol 22, Issue 12. See also Nascimento, H.E.M. and W.F.Laurance. 2002. *Total aboveground biomass in central Amazonian rainforests: a landscape-scale study.* Forest Ecology and Management 168, 311-321. This found 82 per cent of aboveground biomass residing in trees of greater than 10cm diameter. See also Brown, I.F., et al. 1995. *Uncertainty in the biomass of Amazonian forests: An example from Rondônia, Brazil.* Forest Ecology and Management 75, 175-189, which found that that 50 per cent of live aboveground biomass was found in just 3 per cent of the trees.

119 Luyssaert, S., et al. 2008. *Old-growth forests as global carbon sinks.* Nature, Vol 455

120 Sillett, S.C., et al. 2010. *Increasing wood production through old age in tall trees.* Forest Ecology and Management 259 (2010) 976–994.

121 Stephenson, N.L., et al. 2014. *Rate of tree carbon accumulation increases continuously with tree size.* Nature 507, 90–93. *'We present a global analysis of 403 tropical and temperate tree species, showing that for most species mass growth rate increases continuously with tree size. Thus, large, old trees do not act simply as senescent carbon reservoirs but actively fix large amounts of carbon compared to smaller trees… Thus, large, old trees do not act simply as senescent carbon reservoirs but actively fix large amounts of carbon compared to smaller trees; at the extreme, a single big tree can add the same amount of carbon to the forest within a year as is contained in an entire mid-sized tree.'* The paper also notes: *'In absolute terms, trees 100 cm in trunk diameter typically add from 10 kg to 200 kg of aboveground dry mass each year (depending on species), averaging 103 kg per year. This is nearly three times the rate for trees of the same species at 50 cm in diameter, and is the mass equivalent to adding an entirely new tree of 10–20 cm in diameter to the forest each year.'*

122 Keith, H., et al. 2010. *Estimating carbon carrying capacity in natural forest ecosystems across heterogeneous landscapes: addressing sources of error.* Global Change Biology 16, 2971-2989.

123 Keith, H., et al. 2009. *Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests.* PNAS, Vol 106, No 28.

124 Vieira, S., et al. 2005. *Slow growth rates of Amazonian trees: Consequences for carbon cycling.* PNAS, Vol 102, No 51. Found that 17-50 per cent of trees with a diameter of greater than 10cm in plots in central Amazonia have ages exceeding 300 years.

125 See Ghazoul and Sheil, 2010: *'A synthesis of a number of estimates (1992-2006) by forest scientists (from modelling, ring analysis and radiocarbon dating) shows maximum age data for a variety of large broad-leaved tropical rain forest trees that are well above a century: 257 (Thailand), 350 (Guyana), 427 (Bolivia), 608, 650 (Costa Rica), 183, 440, 502, 981, 1370 (Brazil/Central Amazon), 1287 (Sarawak), and 220 (Cameroon).'*

126 Strickland, M.S., et al. 2013. *Trophic cascade alters ecosystem carbon exchange.* PNAS, Vol 110, No 27.

127 Schmitz, O.J., et al. 2013. *Animating the Carbon Cycle*. Ecosystems, DOI: 10.1007.

128 Averill, C., et al. 2014. *Mycorrhiza-mediated competition between plants and decomposers drives soil carbon storage*. Nature 505, 543-545. See also Devitt, A. 2014. *The fungus among us: scientists discover a big player in the global carbon cycle*. Mongabay, 12th March.

129 Bagchi, R., et al. 2014. *Pathogens and insect herbivores drive rainforest plant diversity and composition*. Nature, Vol 506, 6th February.

130 Crowther, T.W., et al. 2014. *Predicting the responsiveness of soil biodiversity to deforestation: a cross-biome study*. Global Change Biology, doi: 10.1111/gcb.12565.

131 See: Strassburg, B., et al. 2009. *Global congruence of carbon storage and biodiversity in terrestrial ecosystems*. Conservation Letters 3 (2010) 98–105; Paquette, A. and C.Messier. 2011. *The effect of biodiversity on tree productivity: from temperate to boreal forests*. Global Ecology and Biogeography, 20, 170–180; and Ruiz-Benito, P., et al. 2014. *Diversity increases carbon storage and tree productivity in Spanish forests*. Global Ecology and Biogeography, 23, 311–322.

132 There is a voluminous literature on these topics. For some starting points, see: Schroth, G., et al. 2004. *Agroforestry and biodiversity conservation in tropical landscapes*. Island Press; www.ecoagriculture.org ; and www.worldagroforestry.org

133 'Secondary' is used as a broad term throughout this report, with a principal meaning of regeneration from a previously logged or otherwise disturbed state. It is also employed to cover forests growing on abandoned agricultural lands.

134 Martin, P.A., et al. 2013. *Carbon pools recover more quickly than plant biodiversity in tropical secondary forests*. Proc R Soc B 280: 20132236. See also Cole, L.E.S., et al. 2014. *Recovery and resilience of tropical forests after disturbance*. Nature Communications, 5:3906, which finds full recovery occurring over longer time-frames: 210 years (median) and 503 years (average). The differing results indicate the need for more research – and more differentiation between species richness and species composition.

135 Jain, A.K., et al. 2013. *CO_2 emissions from land-use change affected more by nitrogen cycle, than by the choice of land-cover data*. Global Change Biology, doi: 10.1111/gcb.12207. For a commentary on the paper, see Pongratz, J. Plant a tree, but tend it well. Nature, Vol 498, 47.

136 Batterman, S.A., et al. 2013. *Key role of symbiotic dinitrogen fixation in tropical forest secondary succession*. Nature, doi:10.1038/nature12525.

137 See: van Breughel, M., et al. 2011. *Estimating carbon stock in secondary forests: Decisions and uncertainties associated with allometric biomass models*. Forest Ecology and Management, Vol 262; Rozendaal, D.M.A. and R.L.Chazdon. 2015. *Demographic drivers of tree biomass change during secondary succession in northeastern Costa Rica*. Ecological Applications (in press); Dent, D.H. and S.J.Wright. 2009. *The future of tropical species in secondary forests: A quantitative review*. Biological Conservation, Vol 142; and Chazdon, R.L. 2014 (a). *Second Growth: The Promise of Tropical Forest Regeneration in an Age of Deforestation*. University of Chicago Press. The latter is a comprehensive and invaluable resource.

138 Spracklen, D. and R.Righelato. 2014. *Tropical montane forests are a larger than expected global carbon store*. Biogeosciences, 11, 2741–2754.

139 See: Donato, D.C., et al. 2011. *Mangroves among the most carbon-rich forests in the tropics*. Nature GeoScience, Vol 4, 3rd April; Hutchison, J., et al. 2013. *Predicting global patterns in mangrove forest biomass*. Conservation Letters, Vol 7, Issue 3, pp233-240; Mcleod, E., et al. 2011. *Blueprint for Blue Carbon: Toward an Improved Understanding of the Role of Vegetated Coastal Habitats in Sequestering CO_2*. Frontiers in Ecology and the Environment, Vol 9, Issue 10; and Pendleton, L., et al. 2012. *Estimating Global 'Blue Carbon' Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems*. PLoS One, 7(9).

140 See: Hooijer, A., et al. 2010. *Current and future CO_2 emissions from drained peatlands in Southeast Asia*. Biogeosciences, 7, 1505–1514; Miettenen, J. and S.C. Liew. 2010. *Status of Peatland Degradation and Development in Sumatra and Kalimantan*. Ambio, 39: 394-401; Gaveau, D.L.A., et al. 2014. *Major atmospheric emissions from peat fires in Southeast Asia during non-drought years: evidence from the 2013 Sumatran fires*. Nature, Scientific Reports, 4 : 6112; Murdiyarso, D., et al. 2010. *Opportunities for reducing greenhouse gas emissions in tropical peatlands*. PNAS, Vol 107, No 46; Page, S.E., et al. 2011. *Global and regional importance of the tropical peatland carbon pool*. Global Change Biology, 17, 798–818; Moore, S., et al. 2013. *Deep instability of deforested tropical peatlands revealed by fluvial organic carbon fluxes*. Nature, Vol 493, 31st January; and Davidson, N.C. 2014. *How much wetland has the world lost – Long-term and recent trends in global wetland area*. Marine and Freshwater Research, 65. The latter finds that 64-71% of global wetlands have been lost since 1900, and the rate of loss may have been as high as 87% since 1700.

141 See Grace, J., et al. 2014.

142 Draper, F.C., et al. 2014. *The distribution and amount of carbon in the largest peatland complex in Amazonia*. Environmental Research Letters, 9, 124017. Estimates Amazonian peat forest carbon stores at more than 3GtC.

143 Sun, Y., et al. 2014. *Impact of mesophyll diffusion on estimated global land CO_2 fertilization*. PNAS, Vol 111, No 44. See also McGrath, M. 2014. *Climate change: Models 'underplay plant CO_2 absorption.'* BBC, 14th October. http://www.bbc.co.uk/news/science-environment-29601644 and Canadell, P. 2014. *Plants absorb more CO_2 than we thought, but …* The Conversation, 15th October. https://theconversation.com/plants-absorb-more-co2-than-we-thought-but-32945

144 Shevliakova, E., et al. 2013. *Historical warming reduced due to enhanced land carbon uptake*. PNAS, Vol 110, No 42.

145 Lewis, S.L., et al. 2009. *Increasing carbon storage in intact Africa tropical forests*. Nature 457, 1003-U3.

146 Van der Sleen, P., et al. 2015. *No growth stimulation of tropical trees by 150 years of CO_2 fertilization but water-use efficiency increased*. Nature Geoscience, Vol 8.

147 Hovenden, M.J., et al. 2014. *Seasonal not annual rainfall determines grassland biomass response to carbon dioxide*. Nature, Vol 511, 31st July.

148 See O'Brien, C.L., et al. 2014. *High sea surface temperatures in tropical warm pools during the Pliocene*. Nature Geoscience, 29th June; Cabot Institute, 2014. *High CO_2 levels cause warming in the tropics*. 29th June; Wang, X., et al. 2014. *A two-fold increase of carbon cycle sensitivity to tropical temperature variations*. Nature, Vol 506, 13th February; and Friend, A.D., et al. 2013. *Carbon residence time dominates uncertainty in terrestrial vegetation responses to future climate and atmospheric CO_2*. PNAS, Vol 111, No 9.

149 Zhang, M., et al. 2014. *Response of surface air temperature to small-scale land clearing across latitudes*. Environmental Research Letters 9.

150 Knorr, W. 2009. *Is the airborne fraction of anthropogenic CO_2 emissions increasing?* Geophysical Research Letters, 36, L21710.

151 Regnier, P., et al. 2013. *Anthropogenic perturbation of the carbon fluxes from land to ocean*. Nature Geoscience 6, 597–607. Finds that there has been a significant increase in the transport of terrestrial carbon into the oceans since 1750.

152 Raupach, M.R., et al. 2014. *The declining uptake rate of atmospheric CO_2 by land and ocean sinks*. Biogeosciences, 11, 3453-3475.

153 See: Klos, P.Z. 2014. *Throughfall heterogeneity in tropical forested landscapes as a focal mechanism for deep percolation*. Journal of Hydrology, Vol 519. This paper finds that 'throughfall' (redistribution of water by plant or tree canopies) achieves deep percolation of tropical forest soils in forests where the canopy is heterogeneous (non-uniform, i.e. mature and rich in species and composition).

154 See: Spracklen, D.V., et al. 2012. *Observations of increased tropical rainfall preceded by air passage over forests.* Nature, 489 (7415), pp.282-5; Aragao, L.E.O.C. 2012. *The rainforest's water pump.* Nature, Vol 489, 13th September; Hilker, T., et al. 2014. *Vegetation dynamics and rainfall sensitivity of the Amazon*. PNAS, Vol 111, No 45, and Butler, R. 2014. *Amazon rainforest is getting drier, confirms another study.* Mongabay, 30th October; Butler, R. 2014. *Facing severe drought, 'war effort' needed to save the Amazon, says scientist*. Mongabay, 3rd November, and Nobre, A. 2014. *O Futuro Climático da Amazônia* INPE. 30th October; and Lawrence, D. and K.Vandecar. 2014. *Effects of Tropical Deforestation on Climate and Agriculture*. Nature Climate Change, 18th December.

155 Lawrence, D. and K.Vandecar. 2014.

156 Butler, R. 2014. *Facing severe drought, 'war effort' needed to save the Amazon, says scientist*. Mongabay, 3rd November. See also Nobre, A. 2014.

157 Bradshaw, C.J.A., et al. 2007. *Global evidence that deforestation amplifies flood risk and severity in the developing world*. Global Change Biology, Vol 13, No 11.

158 Hilker, T., et al. 2014.

159 See: Hilker, T., et al. 2014, Nobre, A. 2014; and Lawrence, D. and K Vandecar. 2014.

160 Lawrence, D. and K.Vandecar. 2014. See also Davidson, E.A., et al. 2012. *The Amazon basin in transition*. Nature, Vol 481, 19th January.

161 See Table 3.2, p41 in: *Climate Change: Financing Global Forests*. 2008. The Eliasch Review. The Stationery Office. Drawn from Grieg-Gran, M. 2008. *The Cost of Avoiding Deforestation: Update of the Report prepared for the Stern Review of the Economics of Climate Change*. This comprehensive (but now somewhat out of date) review found a range of other commodities commanding higher prices than standing forests, including soybean (US$3,200), cocoa (US$1,400), timber (US$1,000), short-fallow food crops (US$800), and beef (US$400).

162 See http://www.indexmundi.com/commodities/?commodity=palm-oil (Accessed 2nd November 2014) for palm oil prices. Annual revenues are reported in a range of US$2,300-US$3,600 per hectare. This derives from per ton prices of US$650-US$825, between April and September.

163 Peters-Stanley, M., et al. 2013. *Covering New Ground: The State of the Forest Carbon Markets*. Ecosystem Marketplace. Assumes deforestation of a hectare containing 200 tons of carbon (734 tonnes of CO_2e) with credits raised evenly over a 30 year period.

164 Marginal opportunity costs are likely to apply in cases where producers forego the opportunity to convert a forest in favour of siting production on already deforested lands. These might include: foregoing timber revenues from initial clearing; investment in land rehabilitation (e.g. because of degraded soils); and financial costs and time factors relating to legal processes which seek to secure the free prior and informed consent of communities living on the lands in question. However, these opportunity costs are likely to be far lower than those pertaining to the deforestation option.

165 Boucher, D. 2008. *Out of the woods: A realistic role for tropical forests in curbing global warming.* Union of Concerned Scientists. *'18 of the 29 estimates are under $2. The 29 estimates range from less than zero to a maximum of $13.34, and all but one are below $10.'*

166 Marcantonini, C. and A.D. Ellerman. 2013. *The Cost of Abating CO_2 Emissions by Renewable Energy Incentives in Germany.* MIT Center for Energy and Environmental Policy Research, CEEPR WP 2013-005. Reports results (for 2006-2010) showing that 'CO_2 abatement cost of wind are relatively low, of the order of tens of Euro per tonne of CO_2, while CO_2 abatement cost of solar are very high, of the order of hundreds of Euro per tonne of CO_2.'

167 Lubowski, R.N. and S.K.Rose. 2013. *The Potential for REDD+: Key Economic Modeling Insights and Issues*. Review of Environmental Economics and Policy, Vol 7, Issue 1, 67-90. See also Kerr, S.C. 2013. *The Economics of International Policy Agreements to Reduce Emissions from Deforestation and Degradation*. Review of Environmental Economics and Policy, Vol 7, Issue 1, 47–66.

168 Pfaff, A., et al. 2013. *Realistic REDD: Improving the Forest Impacts of Domestic Policies in Different Settings*. Review of Environmental Economics and Policy, Vol 7, Issue 1, 114–135.

169 Angelsen, A. and T.Rudel. 2013. *Designing and Implementing Effective REDD+ Policies: A Forest Transition Approach*. Review of Environmental Economics and Policy, Vol 7, Issue 1, 91–113.

170 See New Climate Economy, 2014, chapter 3: *'a major cause of the decline in deforestation in the Brazilian Amazon from 2005 to 2012 was that the government ramped up its enforcement of the Forest Code that set limits on forest clearing. The use of remote sensing to detect infractions in near-real-time, more agents in the field to follow up on those detections, and visible applications of fines and other penalties combined to boost law enforcement at the Amazon forest frontier.'*

171 See Manson, K. 2011. *Kenya corrals its crucial 'water towers'*. Financial Times, 19th September.

172 Dudley, N and S.Stolton. 2003. *Running Pure: The importance of forest protected areas to drinking water.* WWF.

173 Allison, K and A.Currie. 2014. *Brazil's epic water crisis a global wake-up call*. Reuters, 24th November.

174 Teixeira, M. 2014. *Brazil carbon emissions rise for the first time since 2004 – report*. Reuters, 19th November.

175 Lawrence, D. and K.Vandecar. 2014. *'Future agricultural productivity in the tropics is at risk from a deforestation-induced increase in mean temperature and the associated heat extremes and from a decline in mean rainfall or rainfall frequency.'*

176 For a valuable synthesis see Pirard, R. and R.Lepeyre. 2014. *Classifying market-based instruments for ecosystem services: A guide to the literature jungle*. Ecosystem services, Vol 9, pp106-114.

177 Costanza, R., et al. 2014. *Changes in the global value of ecosystem services*. Global Environmental Change 26 (2014) 152–158. Updates the author's earlier paper: Costanza, R., et al. 1997. *The value of the world's ecosystem services and natural capital*. Nature, Vol 387, 15th May.

178 See, for example, Agarwala, M., et al. 2014. *Natural capital accounting and climate change*. Nature Climate Change, Vol 4.

179 Russi, D. and P. ten Brink. 2013. *Natural Capital Accounting and Water Quality: Commitments, Benefits, Needs and Progress*. A Briefing Note. The Economics of Ecosystems and Biodiversity (TEEB).

180 De Groot, R.S., et al. 2013. *Benefits of Investing in Ecosystem Restoration*. Conservation Biology, Volume 27, No. 6, 1286–1293.

181 Mullan, K. 2014. *The Value of Forest Ecosystem Services to Developing Economies*. Center for Global Development. CGD Climate and Forest Paper Series 6.

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382 The BEI has a mission is to lead the banking industry in collectively directing capital towards environmentally and socially sustainable economic development. http://www.cisl.cam.ac.uk/Business-Platforms/Banking-Environment-Initiative.aspx

383 Seen from a longer historical perspective, the trend is hardly new: the environmental history of the tropics since 1492 is a narrative replete with assaults on forests, often by European and North American empires – for timber, rubber, sugar, coffee, bananas, iron ore and other foodstuffs and materials. See, for example: Ferguson, N. 2004. *Empire: How Britain Made the Modern World.* Penguin; Tucker, R.P. 2000. *Insatiable Appetite: The United States and the Ecological Degradation of the Tropical World.* University of California Press; and Williams, M. 2003. *Deforesting the earth: from history to global crisis.* University of Chicago Press; and Dean, W. 1995. *With Broadax and Firebrand: The Destruction of the Brazilian Atlantic Forest.* California University Press.

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degrees of uncertainty (for example, Persson et al [p.26] note a range of uncertainty of 30% for Brazilian beef and Indonesian palm oil); although much of the data draws on peer-reviewed papers covering specific commodities in different geographies, all are reliant to some degree on Hosonuma et al (2012), the most recent pan-tropical meta-study of the attribution of deforestation and degradation to the range of drivers. This found that commercial agriculture is responsible for c.40% of deforestation, a much lower figure than estimated in the above reports. The most striking gap in these new analyses is on deforestation attributable to smallholder and subsistence agriculture, for which Hosonuma remains the principal source.

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The Prince's Charities Foundation registered charity number 1127255

Contact Details

The Prince's Charities' International Sustainability Unit
Clarence House
London
SW1A 1BA

0207 024 5669

beatriz.luraschi@royal.gsx.gov.uk

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