Beyond carbon: realising the value and continued stewardship of tropical forest ecosystem services in a changing climate


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Abstract
Tropical rain forests play an important role in regulating climate and in providing other ‘ecosystem services’ (ES) to humanity. Deforestation leads to the loss of these services, impacting global climate, regional weather and local livelihoods and culture. Recognising these impacts, the UN’s REDD+ mechanism aims to generate incentives to encourage the maintenance or enhancement of tropical forests. REDD+ represents one mechanism whereby forest-dwelling communities may be compensated for their role as forest stewards. We report on the emerging results from a project to analyse ES delivery by rain forest in tropical South America, to investigate the impact of likely climate and land use change this century, and to consider what compensation mechanisms for maintaining the ES (in the face of such changes) are likely to be seen as acceptable by forest-dwelling communities here, and in other tropical regions. Climate projections for the 21st century indicate a risk of substantial changes in ES at local and regional scales, related to changes in global climate change and/or land use. In the case of reduced rainfall, we use the 2005 drought in Amazonia to document the diverse impacts of drought, by quantifying the costs of state-level health treatment and region-wide fire incidence. Compensation mechanisms designed to link forest conservation with the maintenance of ES are likely to be most successful if the range of ES considered is wider than a single metric such as carbon, and if the mode of compensation addresses social and cultural resource needs, as well as financial ones.
Introduction

Tropical rain forests are inextricably linked with global climate, directly through their substantial roles in the exchange of mass and energy with the atmosphere (Bonan, 2008), and indirectly through the impact of deforestation and forest degradation on the atmospheric concentration of greenhouse gases (GHGs), primarily carbon dioxide (CO₂), and on sensible and latent heat flux (Gullison et al. 2007, Bonan 2008). However, their importance to humanity goes far beyond these fundamental climatic metrics. The roles forests also play - the ‘ecosystem services’ (ES) they provide (Costanza 1997) - range from the provision of biodiversity and soil fertility, to cultural heritage and economic sustainability (Shvidenko 2005).

Healthy forests are important natural assets in the livelihood strategies of many of the world’s poorest groups of people (Sunderlin et al. 2008). About 1.2 billion living in extreme poverty are dependent on forests (World Bank 2004). Whilst the protection of natural ecosystems has occasionally been considered capable of creating a poverty trap for indigenous communities (van Gardingen 2003), this has rarely been thought appropriate to tropical rain forests. Instead, the potentially large contribution that halting deforestation could make to reducing global CO₂ emissions (Malhi, Meir and Brown 2003, Gullison et al. 2007) has focused debates surrounding the avoidance of forest loss, ES and potential payments for the retention of ES that could benefit tropical rain forest nations, and the often resource-poor communities dwelling in, and providing stewardship of, their forested regions (Peskett 2008). The concept that maintenance of the ES and related co-benefits from intact tropical rain forests might be compensated for has gained ground rapidly in recent years (Laurance 2007). However, the justification, permanent utility and acceptability of different forms of compensation all remain under close scrutiny, and are linked to national and international policy development (Parker 2008).

Here we examine initial outcomes from a project designed to link expertise across disciplines in the Amazon-Andes region. The aim was to raise research capacity to advance understanding of ES and how projects to implement ‘payment for ecosystem services’ (PES) might work, with particular reference to enhancing or protecting the well-being of forest-dwelling communities in the region. Whilst a key element of the project was to raise the collaborative capital necessary to do this work, a series of outputs were also sought, spanning the policy and economic frameworks (Hall 2009, Araújo 2009, Cranford 2010, Trivedi et al. 2009, Karousakis 2009), the physical science (Marengo et al. 2008, Marengo et al. 2010, Poveda et al. 2004, Meir et al. 2009), and the needs of forest communities in relation to PES (Mattei and Rival, 2009, ESPA AA 2010). We focus here on three questions: (i) how does climate science frame the background of the PES debate in Amazonia? (ii) can the 2005 drought provide examples of economic vulnerability in relation to climatic extremes? (iii) is the concept of PES appropriate for improving the well-being - or reducing the vulnerability to ES loss - of forest dwelling communities in Amazonia and other tropical rain forest regions?

Emerging policy: REDD

Emissions of CO₂ from deforestation and the loss of tropical peat lands contribute approximately 15% of global emissions (van der Werf 2009, IPCC 2007, Ryan 2009). Forest degradation adds a substantial additional efflux (Nepstad et al. 1999, Asner et al. 2006), but this has not been well-quantified globally. Given this large role in
global CO$_2$ emissions, tackling tropical deforestation and forest degradation has been identified as one of the quickest and most cost-effective climate change mitigation options (Stern 2006, Gullison et al. 2007).

The success of efforts to reduce deforestation and forest degradation will depend on the capacity to change the economic land use equation made daily by millions of forest users: whether it is possible to make forests worth more standing than cleared. The value of the global climate regulation service provided by tropical forests has been estimated at roughly US$2000/ha/yr (TEEB 2009) and the challenge therefore is to create an international mechanism – perhaps a Payment for Ecosystem Service (PES) mechanism – to capture that value and transfer it in the form of appropriate incentives to those nations and communities who are maintaining and enhancing their forests.

In combination with a perceived need to control the rise in atmospheric CO$_2$ concentration (IPCC 2007) and an emerging global market in carbon (Stern 2006), the UN policy process ‘REDD’ has been seen as a way to put a greater value on standing forests rather than on their conversion to other land uses (REDD = Reducing Emissions from Deforestation and forest Degradation). REDD has rapidly developed into ‘REDD+’ which is now described as: “Policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries” (UNFCCC Decision 2/CP.13-11). While the initial policy goal was to reduce CO$_2$ emissions from deforestation and forest degradation, the negotiations among nations have broadened its scope to acknowledge the validity of related land use activities. The “+” in REDD+ refers to forest conservation, sustainable forest management and enhancement of forest carbon stocks, e.g. through forest rehabilitation and regeneration (Parker 2008). Enlarging the area of forests through afforestation and reforestation (A/R, which is part of the Clean Development Mechanism, an instrument of the earlier Kyoto Protocol to the UNFCCC), also increases forest carbon stocks, but it is not clear whether A/R will be part of REDD+.

The development of REDD+ incorporated and substantially widened some ideas from the Clean Development Mechanism, and also recognised the multiple ES co-benefits that forests provide. The evolution of REDD+ is likely to continue following the recent UN Climate Conference in Copenhagen (LCA Draft Decision FCCC/AWGLCA/2009) and the South American tropics provide an excellent example of this debate as rates and modes of forest loss vary within and among countries such as Brazil, Peru, Ecuador and Guyana, as do land use opportunities (ESPA-AA 2008, Trivedi et al. 2009).

**Climate, Carbon and Water**

The ES impact of the CO$_2$ emissions from deforestation and biomass burning operates at a global scale and is why the REDD policy process focuses on carbon. However, tropical forests perform climatic ES at other scales. Maximum air temperatures, and the diurnal range in air temperature both tend to be less extreme over continuous rain forest than pasture, and the evaporation of moisture into the atmosphere is substantially larger because of both greater soil water access by deep rooting trees, and the rougher surface of the forest canopy (Culf et al., 1995). Locally, deforestation
can result in higher precipitation in some areas, because of small-scale effects on convection (Correia et al. 2008, Werth and Avissar 2002), although overall, rainfall totals seem to be lower (IPCC 2007, Marengo 2006). At large scale, however, widespread forest conversion to pasture and agriculture is expected to reduce rainfall in the region and increase temperatures by reducing the amount of evaporative cooling and altering cloud cover (Werth and Avissar 2002; Chagnon and Bras 2005; Costa et al. 2007; Nobre et al. 1991, Sampaio et al. 2007) and, potentially, because of the increased regional atmospheric aerosol loading from land use change (Betts et al. 2008, IPCC 2007).

Drought has become a touch-stone issue for environmental science and governance in Amazonia for at least three reasons: (i) the recent occurrence of severe droughts in 1998 and 2005 (Marengo et al. 2009, Marengo et al. 2008); (ii) the projections of long term climatic drying in the region (Christensen et al. 2007); and (iii) because of the potential impact of drought on forest functioning and the ES supplied by rain forest (Betts et al. 2004, Meir et al. 2009). Although climate models differ in their scenarios for the 21st century, multi-model analyses have tended to show good agreement in warming trends across tropical South America, and 20-70% agreement in scenarios of substantial precipitation reductions, especially in the east of Amazonia (Fig. 1a; Christensen et al. 2007, Malhi et al. 2008, Marengo et al. 2009). Experimental and observational evidence for the impacts of severe drought on forest functioning do not yet extend much beyond a 5-10 year timeframe, but indicate rapid and potentially strong reductions in transpiration (30-40%) and gross primary productivity (10-15%), accompanied after a period of resistance to drought, by increases in mortality and large reductions in above ground biomass (Fisher et al. 2007, Nepstad et al. 2007, Meir et al. 2009, Phillips et al. 2009). Whether or not a secular change to a much drier climate will induce large scale vegetation change from forest to savanna this century remains difficult to test directly. The indications from modelling and experimental studies (Sampaio et al. 2007, Oyama and Nobre 2003, Costa et al. 2010) suggest that some form of tipping point in climate and vegetation is possible, perhaps after deforestation exceeds 40% (Sampaio et al. 2007, Malhi et al. 2009, Nobre and Borma 2009), although the capacity of dynamic vegetation models to capture the response to drought currently remains poor (Galbraith et al. 2010). Feedbacks associated with expected land use change and fire incidence will almost certainly enhance any trends set in place by climatic change (Golding and Betts 2008, Araujo et al. 2007, Nobre and Borma 2009), increasing the likelihood of forest loss under a business as usual development scenario for the region (Soares Filho et al. 2006).

At large scale, climate change resulting from deforestation and the increase of GHG concentrations could interrupt or alter moisture transport from the Amazon region to southeastern South America, where the economically important Rio de La Plata river basin is located (Soares and Marengo 2008). The recycling of water between land and atmosphere via repeated evaporation, convection and precipitation, is intensified over forest. Thus, a substantial proportion of water vapour originating in the tropical Atlantic Ocean and transported by trade winds eastwards towards South America, is repeatedly recycled as air masses move over forest towards the Andes. Perhaps 25-50% of rainfall in the region is recycled in this way (Eltahir and Bras 1994, Marengo 2006). This east-west air current is deflected south-east by the Andes, forming the South American Low Level Jet (SALLJ) and supplying warm moist air to the
mesoscale convective systems that generate rainfall in the vast Plata river basin (Marengo et al. 2004).

The Plata basin covers nearly one-fifth of South America, including parts of Argentina, Bolivia, Brazil, Paraguay, and Uruguay. It supports more than 100 million people and produces about 70% of the total GNP of the five basin countries, equivalent to US$1 trillion in 2004. Numerous hydroelectric plants provide three-quarters of the region’s energy, while agriculture and livestock are among the region’s most important resources (Vera et al. 2006). The SALLJ transports considerable amounts of moisture from Amazonia to the basin (Vera et al. 2006, Marengo et al. 2004), supporting drinking water, agricultural and hydroelectric concerns. If deforestation in eastern Amazonia, where land use pressure is highest, was complete enough to provide a barrier to the transport of recycled moisture to the SALLJ, it is possible that the amount of moisture transported via the SALLJ could be altered, by increasing either the frequency or the intensity of the SALLJ events, causing both long dry spells and very intense rainfall events (Soares and Marengo 2008, da Silva et al. 2008). Preliminary research as part of this capacity-building project indicates that precipitation changes, in amount, intensity and distribution in La Plata Basin could have significant economic impacts, but more research is required to estimate the potential regional costs of different forest loss-precipitation change scenarios (Cranford et al. 2010), in addition to the direct consequences of such changes on ES supply for local populations within Amazonia.

Despite its importance there remains uncertainty in the magnitude of this regional-scale moisture transport mechanism, its variability and its sensitivity to deforestation and climate change in Amazonia (Sampaio et al. 2007, da Silva et al. 2008). These questions contribute to an ongoing research agenda addressing regional climate science and forest ecosystem science in South America (Keller et al. 2009). For now, the severity of the impacts of global climate change and/or deforestation on ES supply at community or regional scales remain difficult to quantify with high precision, but a risk of their loss is widely and increasingly acknowledged. The REDD+ policy framework and related PES mechanisms address this risk by incentivising the maintenance or enhancement of rain forest ecosystems, and thus promoting the practice of the precautionary principle in relation to the avoidance of declines in ES from tropical rain forests, and their associated co-benefits.

**The 2005 drought in Amazonia**

Extreme changes in precipitation – drought or intense rainfall events – both have the potential for negative impacts on communities and local or regional economies. The recent 2005 drought in Amazonia, provides one example. During 2005, the south-western and western portions of Amazonia experienced one of their driest periods in 60 years, compounded by extensive forest fires. Although previous recent droughts in the region have been associated with El Niño Southern Oscillation, the cause of the 2005 drought was warmer global temperatures, leading to raised sea surface temperatures in the northern tropical Atlantic Ocean, and ultimately lower rainfall in Amazonia (Marengo et al. 2008, Cox et al. 2008). The diminished rainfall resulted in exceptionally low water levels in the Amazon river, draining many floodplain lakes and streams and isolating hundreds of riverine villages and communities. The government called a state of emergency and mobilized the army to provide water and medical supplies to these communities and to contend with the intense forest fires in
Brazil’s western state of Acre (Brown 2006). Many fires were clustered close to forest edges, indicating that human activities made the forest more fire prone (Aragão et al. 2007). The drought led to substantial CO$_2$ emissions from forest to atmosphere through increased fire incidence (Aragao et al. 2007) and widespread increased tree mortality (Phillips et al. 2009).

Our preliminary analyses of the economic costs of the 2005 drought indicate that the impacts were felt across multiple sectors supported by rain forest ES, including: river fisheries, human health, agricultural production and river transport. The emerging picture is that within the Amazon region the impacts were severe at both regional and local levels. We illustrate this here with analysis of the impacts on health and fire incidence. Compilation of data from Brazil’s health service (www.datasus.gov.br) on the costs of treating waterborne diseases in Acre State, Brazil, where the drought was felt particularly strongly, indicate a large (up to 2-fold) increase in the cost of treating water-borne diseases at the time of the drought (Fig. 2). Similarly, colonized and developing regions across Amazonia showed an increase in fire incidence during 2005, particularly in Acre State (Fig. 3). These data demonstrate a high vulnerability within Amazonian communities to the impacts of drought, and a high associated cost with their management. Increasing the ability to resist and mitigate the impacts of such change (Nepstad et al. 2001) is likely to be a priority for regional governments and local communities alike. A PES system that contributed to reducing vulnerability to such ES loss might thus be very attractive, if it was considered acceptable and workable.

Can PES work?
Unlike many previous attempts to conserve forests, a core component of REDD+ is performance-based compensation or payments for ecosystem services (Angelsen 2009) at the international level. While REDD+ has been formulated as an international financing mechanism enacted by participating nations, it is dependent on reinforcing or modifying the activities of local forest users through the delivery of incentives for conservation. Thus, a link is made between international financing for ES (climate regulation) at large scale, with action on the ground and a multivalent suite of ES at local scales.

The REDD+ mechanism will need to find a way to encompass the different perspectives of global and regional beneficiaries and local service providers within a form of PES. PES schemes have been defined as: (1) voluntary transactions where (2) a well-defined ES is (3) being “bought” by a minimum of one ES buyer (4) from a minimum of one ES provider, (5) if and only if the ES provider secures ES provision (conditionality; Wunder, 2005). Few schemes conform to this definition, leading Sommerville et al. (2009) to define PES as approaches that aim to: (1) transfer positive incentives to environmental service providers that are (2) conditional on the provision of the service, where successful implementation is based on a consideration of additionality and varying institutional contexts. This broader framework focuses attention on the two key aspects of PES – positive incentives and conditionality – that also define REDD+. Hence, it should be possible to learn lessons for REDD+ from existing local and regional PES schemes (Wunder, 2009).

A global review of different PES projects is beyond the scope of this paper (see Landell-Mills 2002, Wunder 2008) but a key question emerges as to how the new
resources required to encourage enhanced or changed behaviour patterns are best derived and then made available within different PES schemes (Cranford & Mourato 2010, Meridian Institute 2009). According to Wunder (2009), few formal performance evaluations of PES schemes have been made so far, but there is already some evidence that well-designed schemes can result in efficient, cost-effective and equitable conservation (Wunder 2008). Property rights assigned to individuals or communities are a prerequisite for the establishment of PES systems, but property rights are often unclear, overlapping and contested in Amazonia’s arc of deforestation (e.g. Börner et al. 2007). Therefore, in the short to medium term, national REDD+ strategies will have to rely heavily on policies other than PES (Angelsen 2009). Nevertheless, several REDD+ demonstration schemes involving local communities in PES are underway across Amazonia (Cenamo 2009), from which lessons can be learned for future large-scale implementation activities (e.g. Hall 2008).

Where studied, indigenous lands and community-conserved areas have proved equally or more effective as nationally governed protected areas in reducing deforestation (Nepstad et al. 2006, Ellis 2008). This has given rise to calls for the inclusion of indigenous lands and protected areas (ILPAs) within REDD+ efforts in Amazonia (Ricketts et al. 2010), with communities receiving compensation/payment for their role as forest stewards and monitors. As part of this capacity-building project, 25 representatives of networks of more than 600 community groups from across the Amazon-Andes shared their experiences of PES schemes. A view prevailed that whilst traditional forest management systems delivered multiple ecosystem services (from cultural, through provisioning to economic resources), current policy often did not support these activities, preventing poverty reduction activities and enhancing vulnerability to (exogenous) changes in climate or land use (GTA CNS 2009). Furthermore, community leaders proposed that incentives for continued forest conservation should take the form of improvements in social policy and services oriented towards education, health, and community social organisation. Among the communities represented (GTA CNS 2009), it was felt that this form of compensation - to increase social capital - was preferable to, and more effective than direct payments.

The state of Acre in south-western Amazonia, Brazil, provides an example of the more holistic interpretation of PES/REDD+ espoused by this large group of community leaders. The state government of Acre is planning to introduce a REDD+ scheme that will increase farmers’ incomes by supporting the recuperation of degraded areas, sustainable agrarian systems and protection measures in six vulnerable areas\(^1\). As part of state programmes for adding value to production, and certifying its sustainability, emphasis will be placed on technical assistance rather than direct payments, with a view to strengthening extractivism (Hall 2009). This view of a PES system that is flexible with respect to the needs of communities and different community members, and to the ES that are enhanced (or protected) by the new activities, appears to have met with success in very different circumstances. For example, the Bolsa Floresta programme of the Fundação Amazonas Sustentável (Viana 2008, 2009) in Brazil and the Miombo Community Land Use & Carbon Management Project in Mozambique (Grace et al. 2009) have both demonstrated how

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\(^1\) ‘Serviços ambientais reduzirão emissões de carbono no Acre’. 
http://www.amazonia.org.br/noticias/noticia.cfm?id=323169 Accessed 14.11.09
new resources can provide accepted incentives to enhance forest or woodland conservation and expansion. Importantly, they both also demonstrate how new resources are most effective when invested to increase local social capital, such as the capacity for local communities to manage and benefit from their forest resource independently, rather than only from an increased availability of external financial resources.

What is needed now is a wider analysis of the relative merits of direct cash payments versus indirect social improvements and technical support in building the resilience of forest-dependent communities to ES loss through exogenous change in climate or land use. The outcome is likely to vary regionally and may partly depend on how REDD+ policy develops, and also on how different development paradigms (e.g. Nobre et al. 2008) are favoured in different regions. However, the process of matching the cultural, environmental and social determinants of human decision making over land use, to the supply of economic and ES resources will be central to any policy that successfully reduces poverty and/or vulnerability to ES loss in forest-dwelling communities, whilst also meeting international climate objectives.

Conclusions
Following the 2009 UN CoP-15 Climate Conference in Copenhagen, the REDD+ policy process is likely to develop rapidly. Although it is only one form of PES, the international financing associated with REDD+ means it has obvious potential for global influence on land use decision making in tropical rain forest regions.

In the context of South America, the scientific basis for justifying some form of PES is strong at both regional and local scales, partly because of recognition of the importance of at least one large-scale ES beyond carbon, namely water. The risk of local and regional economic consequences resulting from substantial changes in rainfall patterns, especially those leading to drought, are widely acknowledged, together with the risk of positive feedbacks among 21st century climate, deforestation and vegetation functioning.

Although we highlight emerging understanding of these questions (Figs 1-3), there remain significant research gaps needed to support policy in relation to PES. As for the most appropriate structure of PES mechanisms designed to reduce poverty or reduce vulnerability of forest-dwelling communities to the loss of ES, the emerging picture is one of flexibility, whereby: (i) the metrics of ES should refer to a bundle of services rather than single metrics such as carbon storage; and (ii) compensation for the maintenance of these ES should result in increased resilience of the people-forest relationship. The appropriate mode of compensation in any PES mechanism must be sensitive to the cultural and economic circumstances of any individual community. However, the provision of resources that first increase social capital and strengthen sustainable economic resilience represents a global common denominator to which all PES mechanisms are likely to need to adhere.
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FIGURE DESCRIPTIONS

**Fig. 1a.** Projected climate change over Brazil by the 2080s relative to 1961-1990 associated with different levels of global warming. These projections used the UK Meteorological Office global climate model and INPE regional climate model driven by different CO2 emissions scenarios using different model variants to assess uncertainties in climate response. Projected global warming is within the range projected by other models, and the projection of faster warming over Brazil in comparison to the global average warming is also made by other models. Regional rainfall responses to global warming vary widely between different models; the UK Met Office model predicts greater than average rainfall reductions, but there is inter-model agreement in the prediction of reduced rainfall the region during the 21st century (see text). If the general pattern is for global warming to decrease rainfall in north and north-east Brazil (as shown here for the December-January-February season), greater global warming results in greater reductions in rainfall. From top to bottom, the emissions scenarios are the IPCC SRES scenarios A1FI, A1B, and B1; the B1 projection shown here uses a model with lower climate sensitivity.

**Fig 1b.** Simulated impacts of deforestation on rainfall in Amazonia (from Sampaio et al. 2007). The curves show the fraction of rainfall in eastern Amazonia for different levels of deforestation across the whole of Amazonia, compared to the original forest extent, for each season. In the model, deforested land was converted to soybean plantations. These results were generated with the INPE global climate model which has a low resolution; the Met Office’s regional climate model PRECIS is being used to repeat this study at higher resolution, and to assess the resulting impacts on the remaining areas of intact forest and water resources.

**Fig. 2.** Monthly costs in Brazilian reais (R$) of treating waterborne diseases in Acre State, Brazil, 2000-2007 (columns) and the coincident rainfall anomaly (z-scores; dots and lines). The data from Sistema Único de Saúde (SUS; www.datasus.gov.br) indicate a spike in costs during 2005; comparing by month this spike is up to 100% larger than experienced in any other year under study.

**Fig. 3.** Fire incidence (‘hot’ pixels) and the 2005 drought in Amazonia. Hot pixels indicate the highest positive anomalies during 2005, while rainfall anomalies indicate minimum values during 2005. The coincidence of anomalously high hot pixels in the southwest region of Amazonia, particularly in the State of Acre was coincident with areas of anomalously low rainfall during the drought period. Anomalies were calculated as z-scores and are significant at 95% when values are lower or higher than 1.96. Rainfall data are from TRMM (http://trmm.gsfc.nasa.gov/data_dir/data.html).
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Fig. 1a
Fig. 1b

![Graph showing the relationship between deforestation area and relative precipitation.](image_url)

The graph illustrates the decrease in relative precipitation as the deforestation area increases. Different seasons (DJF, MAM, JJA, SON) show distinct trends in the reduction of precipitation.
Fig. 2.
Fig. 3.