Tipping Points-00-p.qxd 4/4/13 10:48 Page 127

# 4.3
# The Amazon in transition

## *The challenge of transforming the world's largest tropical forest biome into a sustainable social-ecological system*

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### Setting

This chapter considers the fate of the Amazon as an integrated social-ecological system that during the last half a century has undergone an unprecedented period of change and disruption. The Amazon is a biome of truly global significance. Its total area is approximately 6.9 million km$^2$ and encompasses nine countries (Barthem *et al.* 2004). While 69 per cent of the biome is within Brazil, the Amazon also makes up 66 per cent, 60 per cent and 47 per cent of the total landmass of Bolivia, Peru and Ecuador respectively (Barthem *et al.* 2004). The Amazon basin discharges approximately one-fifth of the world's fresh water, provides a home and resources for more than 31 million people, as well as hosting a significant proportion of the world's terrestrial biodiversity (FAO 2011). Indeed, the Amazon has been described as the ultimate 'ecoutility', providing critical ecosystem services on local to global scales (Trivedi *et al.* 2009). The total amount of carbon stored in remaining forests across all of Amazonia (120 ± 30 billion tonnes; Malhi *et al.* 2006) is approximately equivalent to a decade of accumulated human-induced carbon emissions for the entire planet (Canadell *et al.* 2007). Amazonian forests absorb vast amounts of solar energy through the cooling effect of annually releasing trillions of tonnes of water to the atmosphere. This drives atmospheric circulation across the tropics, as well as being responsible for recycling between

Tipping Points-00-p.qxd 4/4/13 10:48 Page 128



one-quarter and one-half of the region's rainfall (Elthahir and Bras 1994; Marengo *et al.* 2011). In addition, the water vapour released by the Amazon also moderates regional weather conditions and supplies rainfall for southern Brazil and the La Plata Basin, the economic powerhouse of Latin America, on which US $1 trillion per year of agribusiness, hydropower, and industry depends (Marengo *et al.* 2011).

The fate of the Amazon is currently at a crossroads. The last four decades have witnessed widespread deforestation across the entire basin (Perz *et al.* 2005; Etter *et al.* 2008; FAO 2011), with some 775,000 km$^2$ of Amazon forests having already been cleared in Brazil alone since 1988 (www.inpe.gov.br). More recently, falling deforestation rates in Brazil since 2005 have generated considerable international praise, giving rise to the notion that Brazil may be one of first countries to achieve the status of a major economic power without destroying most of its forests (Davidson *et al.* 2012). Set against this positive outlook, a burgeoning number of studies have raised the spectre of the Amazon system facing a regime shift or tipping point, whereby a combination of global warming, continued deforestation, an increased frequency of severe drought events, unsustainable timber extraction, and an increased prevalence of fire is set to drive a vicious, and potentially irreversible positive feedback loop, leading to the loss or degradation of a significant proportion of remaining forest (Davidson *et al.* 2012). Here I use research on the prospect of Amazonian forest dieback as an entry point to a broader discussion concerning the Amazon as a complex social-ecological system undergoing an unprecedented process of transition. Drawing on work from across the natural and social sciences, and my own personal experiences working in the eastern Amazon, I then consider how this evermore dynamic system presents particular challenges for societal, governmental and scientific efforts to develop a more environmentally sustainable and socially progressive model of development for the region.

## Climate change, deforestation, and dieback of the Amazon forest

Variation in moisture availability affects the productivity and resilience of tropical ecosystems more profoundly than any other aspect of the climate (Meir and Woodward 2010), meaning that reductions in precipitation and increases in the frequency of severe drought represent a major threat to the

Tipping Points-00-p.qxd 4/4/13 10:48 Page 129



future of tropical forests (Marengo *et al.* 2011). Because of the sheer size of the Amazon rainforest even small changes in forest dynamics can have a significant impact on atmospheric $CO_2$ concentrations, and therefore on the rate of climate change itself. Climate modelling work has suggested two mechanisms that have the potential to drive widespread declines in precipitation across the Amazon, raising the spectre of a potentially irreversible shift towards a system that is only capable of supporting an impoverished secondary or savannah-type vegetation state (Cox *et al.* 2004; Nobre and Borma 2009; Malhi *et al.* 2009; Marengo *et al.* 2011). First, while there is considerable uncertainty in the predictions of different global circulation models (GCMs) there is some evidence to suggest an increase in the likelihood of drought-like conditions for Eastern and Southern Amazonia following twenty-first century warming (Betts *et al.* 2004; Jupp *et al.* 2010). Second, because the Amazon recycles as much as half of its own rainfall, if a sufficient area of forest is cleared, it may be unable to sustain itself in its current form. These models indicate that a threshold or tipping point could be reached via either mechanism, with a 3–4 °C temperature rise or 30–40 per cent level of regional deforestation potentially being sufficient to precipitate large-scale vegetation dieback (Nobre and Borma 2009).

Despite the widespread scientific and media attention these predictions have attracted, confidence in our ability to identify such a threshold or tipping point is marred by uncertainty in both climate change predictions themselves (Jupp *et al.* 2010; Poulter *et al.* 2010) and ecosystem responses to changes in climatic conditions. Regarding ecosystem responses, considerable uncertainty exists in the potential for a compensation effect from $CO_2$ fertilization on plant growth, and water loss through transpiration (Rammig *et al.* 2010; Meir and Woodward 2010). However, irrespective of debates regarding the potential resilience of intact forests to long-term declines in rainfall (see Meir and Woodward 2010), the Amazon is clearly vulnerable to extreme drought events (Phillips *et al.* 2009; da Costa *et al.* 2010). The Amazon suffered from two of the severest drought events on record in 2005 and 2010 (driven by increases in high-Atlantic sea surface temperatures) which resulted in a total $CO_2$ impact from reduced growth and increased tree mortality that was estimated to be potentially equivalent to the net carbon uptake by intact Amazonian forests for the whole decade (Lewis *et al.* 2011). It is possible that these two droughts alone resulted in the biome shifting from a net sink (Phillips *et al.* 1998) to a net source of carbon dioxide (equating to *c.*4 billion tonnes of carbon; Phillips *et al.* 2009; Lewis *et al.* 2011).

Both short- and long-term changes in climatic conditions and moisture stress present major threats to the integrity of Amazon ecosystems. However, it is impossible to disentangle their impact from ongoing patterns of deforestation and forest degradation associated with the expansion of agriculture, roads, and timber harvesting across the basin (Malhi *et al.* 2009; Davidson *et al.* 2012). Indeed, it is now broadly accepted that the greatest threat of a positive feedback cycle capable of driving the widespread and near-term loss or degradation of the Amazon forest comes, not from global and continental-scale changes in climate, but from the interaction between changes in both climate and local human activity – and specifically a rise in the occurrence and intensity of forest fires (Nepstad *et al.* 2001, 2008; Aragão *et al.* 2008). Most tropical rainforest tree species are poorly adapted to fire stress, and even low-intensity surface fires can lead to significant levels of mortality among adult trees (Barlow *et al.* 2002), with repeat burns having the potential to drive an almost complete turnover in tree species composition (Barlow and Peres 2008).

Conditions across much of the Amazon are now approaching something of a 'perfect storm' for driving widespread forest degradation, with an increasingly large area subject to a combination of: high levels of tree mortality from drought, fire, fragmentation, and logging impacts; an increased risk of recurrent fires from the drier and more flammable fuel loads (including drier litter and an increased dominance of understory grasses) that characterize partially degraded forests; and an increase in the number and frequency of ignition sources from the expansion of agriculture and road networks (Nepstad *et al.* 2008).

Attempts to incorporate fire dynamics alongside climate and deforestation modelling suggest that 'business as usual' scenarios of regional development may lead to a doubling of forest fires outside of protected areas in years of extreme drought, and an expanding fire risk to much of the Amazon, including the currently isolated north-western Amazon, by the middle of this century (Golding and Betts 2008; Silvestrini *et al.* 2011). Once the process of forest degradation has started, multiple and reinforcing feedback effects can lead to: (1) a runaway cycle of increased forest vulnerability and impoverishment, driven by fires and repeated and unsustainable logging cycles at local scales, (2) the inhibition of regional rainfall patterns from ongoing forest clearance and increased atmospheric smoke, and (3) feedback effects of elevated $CO_2$ emissions on the global climate system, resulting in further increases in temperature and the likelihood of more frequent and severe drought events, with associated impacts on soil

Tipping Points-00-p.qxd 4/4/13 10:48 Page 131



respiration, tree mortality, and fire dynamics (Nepstad *et al.* 2001; Davidson *et al.* 2012). The type of vegetation that is capable of withstanding this unprecedented onslaught bears no resemblance to a species-rich closed-canopy rainforest. Instead it is better characterized by the young secondary forests that are commonly found on degraded pastures – dominated by pioneer species with low biomass and negligible economic value, and only capable of supporting a tiny fraction of the original forest biota.

## Expanding the tipping point metaphor: the Amazon as a social-ecological system in transition

The notion of a tipping point has been very effective in drawing attention to the increasing vulnerability of the Amazon rainforest, and the close coupling between the forest and global climate systems (Nobre and Borma 2009). However, in keeping with what has been shown by research on the resilience of a wide range of social-ecological systems (Folke *et al.* 2010), it is clear that the fate of the Amazon does not depend on some threshold change in a key system variable (e.g. atmospheric temperature, precipitation, or accumulated forest loss), but rather on a complex interplay of drivers and positive feedback loops that operate at landscape, continental, and global scales. Indeed, an exaggerated policy focus on a precise numerical tipping point can be both distracting and misleading insofar as it suggests that an individual basin-wide driver can be responsible for a change in system state, that degradation below a certain level is 'safe', and that improvements beyond that level are of no value (Davidson *et al.* 2012).

Despite scientific uncertainty regarding natural hydrological and biogeochemical cycles, projections of climate and land use change, their interaction effects and ecosystem responses to changing conditions, an increasingly large proportion of the Amazon is affected by the combined effects of deforestation and forest degradation. This process of change has taken place against a backdrop of social, political and economic change that has transformed the Amazon as a place to live over the course of the last fifty years, with rapid increases in population and widespread migration underpinned by regional economic growth, agricultural expansion and diversification, exploration of new mineral, oil, and gas resources, major infrastructure projects, and political and legal reform (Barthem *et al.* 2004; Killeen 2007; FAO 2011).

Tipping Points-00-p.qxd 4/4/13 10:48 Page 132



Encouragingly, deforestation rates dropped rapidly from 2006 to 2011, with a 56 per cent decline in the annual rate of forest loss in 2006–11 compared to 2001–05 (www.inpe.gov.br). This change has offered some hope that the ambitious deforestation reduction target to 20 per cent of baseline levels (1996–2005) by 2020, announced by former President Lula in the Copenhagen climate change summit as part of Brazil's national climate change action plan, is possible. Indeed, it has even prompted proposals that the end of deforestation is feasible within the same period (Nepstad *et al.* 2009). However, despite the attractiveness and tantalizing nature of this proposal there are a number of reasons why we cannot afford to be complacent about the future of the Amazon, and why a general shift towards a low-emission trajectory of rural development is far from assured (Nepstad *et al.* 2011).

Assessments of alternative scenarios for regional development require consideration of two characteristic features of recent social and ecological changes in system dynamics: (1) an acceleration in the speed of many processes of change, and (2) an increase in the interconnectedness of changes at local, landscape, and regional scales.

One of the most important and far-reaching changes in the Amazon has been the increase in human population. Often perceived as a space for absorbing the population and development problems of other regions, government resettlement and incentive schemes and infrastructure projects have all contributed towards a massive increase and redistribution of people across the basin during the last half a century. Between 1980 and 2000 alone the population of the Brazilian Legal Amazon approximately doubled from 12 to 21 million people, with increases of comparable magnitude in Bolivia, Colombia, Ecuador, and Peru (Perz *et al.* 2005), resulting in a regional population today that exceeds 31 million (FAO 2011). Whilst links between population growth and deforestation are complex (Perz *et al.* 2005; Hecht 2010) this dramatic change has driven increased demand for land and natural resources, as well as increased investment in infrastructure and energy projects, as regions of the Amazon have become increasingly connected with national and international markets (Nepstad *et al.* 2006; Killeen 2007; Lambin and Meyfroidt 2011). The majority of recent population growth in the Amazon has occurred in cities (Guedes *et al.* 2009), many of which have also witnessed rapid rates of economic growth. For example, between 1970 and 2000 the average rate of growth per decade of urban Gross Domestic Product per capita was 85 per cent for cities in the Brazilian Amazon, compared to only 76 per cent for the rest of the country

Tipping Points-00-p.qxd 4/4/13 10:48 Page 133



(www.ibge.gov.br). Whilst urbanization and agricultural intensification have led to a partial decoupling of deforestation and population growth, continued increases in the size and consumption levels of urban populations have contributed towards the strengthening of rural–urban linkages, and rising demand for agricultural commodities, particularly beef (McAlpine *et al.* 2009).

Coupled with the increase in size and wealth of regional populations, as well as the increased connection with international commodity markets (Lambin and Meyfroidt 2011), one of the most important threats facing efforts to reduce deforestation and forest degradation comes from rising prices of agricultural commodities. Such price rises can make deforestation more profitable and may weaken the resolve of local, regional and state government actors to enforce or maintain strict environmental legislation. Evidence for such a change can be seen in the recent negotiations to revise the Brazilian forest code, the law that governs environmental protection on private land, in response to strong lobbying from the agribusiness sector. The potential for a reversal of falling deforestation rates due to future agricultural development and changes in international markets can be observed from the peak of forest loss that occurred between 2002 and 2004 during a rapid increase in the Amazonian cattle herd, and the first large-scale expansion of industrialized agriculture to many parts of the Brazilian Amazon, which resulted in the clearance of 75,000 km$^2$ of forest in Brazil alone – equivalent to 95 per cent of the total area of forest that has been cleared since (2005–2011) (www.inpe.gov.br). The fact that projected demands for both cattle and biofuels are set to exceed the area of land legally available for agricultural expansion by 2020 (Walker 2011) indicates that the system remains highly vulnerable to economic incentives. That said, recent evidence of deforestation rates becoming decoupled from soy production in southern Mato Grosso suggest that improvements in farming techniques and regulation of land use have the potential to dampen fluctuations in forest losses (Macedo *et al.* 2012).

Finally, the profit incentive to expand agriculture into remaining areas of forest may be exacerbated further if much publicized incentives for forest conservation through carbon payments are not forthcoming, and current expectations are replaced by an erosion of credibility and increasing resentment within the agricultural and forestry sectors.

The sensitivity of Amazonian agriculture to short-term changes in market prices also underpins a high level of instability and non-linear behaviour in rural development trajectories (Rodrigues *et al.* 2009) as well

Tipping Points-00-p.qxd 4/4/13 10:48 Page 134



as contributing towards a highly mobile rural population (Brondizio and Moran 2008; Carrero and Fearnside 2011). This population mobility results in a high turnover rate of farm managers and workers, lowering the capacity to adapt to novel circumstances (such as droughts and price fluctuations in particular crops) as newcomers invariably lack a nuanced understanding of local ecological systems and social or economic networks (Brondizio and Moran 2008). Intra-regional mixing of rural populations in areas that often lack any clear system of property rights can also give rise to so-called 'contentious' land use change, driven by antagonism and conflict within and between large landowners and the rural poor – a dynamic which can greatly exacerbate attempts to improve land management practices (Aldrich *et al.* 2012).

In addition to increases in the rate of change of demographic, economic and environmental variables, the second factor to cast uncertainty over the future development trajectories of the Amazon is an increased level of interconnectedness amongst system elements. Research in recent decades has revealed an increasing number of strong and cross-scale connections in the drivers of deforestation and land use change with resonance at global, national and regional scales.

Perhaps the most commonly cited example of a cross-scale connection exerting a powerful influence on the dynamics of rural development in the Amazon is the existence of so-called 'teleconnections', phenomena that appear to be coupled, but take place in geographically distant places on the planet. These include economic signals from other parts of the world – such as trade-bans on beef export by the European Union following the outbreak of foot and mouth disease or sky-rocketing demands for soybean imports by China – which can play a potentially important (Nepstad *et al.* 2006; Hargrave and Kis-Kato 2011), albeit complex role (Ewers *et al.* 2008) in determining rates of change in agricultural expansion and deforestation. Another important (though less appreciated) economic signal to have emerged from an increasingly interconnected global commodities market is the fluctuation of exchange rates between the currencies of Amazon nations and the US dollar. For example, Richards *et al.* (2012) present evidence to suggest that the recent devaluation of the dollar and appreciation of the Brazilian real have counteracted a recent rise in global soybean prices, and in the process, spared an estimated 40,000 km$^2$ of new cropland in the Amazon region alone. At the regional scale the process of indirect land use change, where the expansion of more profitable mechanized farming can displace existing cattle pastures and smallholder

Tipping Points-00-p.qxd 4/4/13 10:48 Page 135



farmers to the deforestation frontier, has long been posited as a threat to the Amazon. Indeed, Arima *et al.* (2011) found that for the period 2003–2008 a 10 per cent reduction in the expansion of soy into previously colonized landscapes could have reduced deforestation by as much as 40 per cent in the heavily forested counties of the Brazilian Amazon. Sharp fluctuations in economic opportunity across the Amazon, driven in part by strong cross-scale interactions in the price of land and the profitability of farming, also contribute towards a highly dynamic human population. Although endogenous birth rates are now the primary driver of population growth in the Amazon region, in-migration is still continuing and there is a very high level of migratory circulation within the region itself (Perz *et al.* 2010a).

One consequence of recent increases in the speed and connectivity of land use changes across the Amazon is the increased likelihood of cascading effects, whether negative or positive, of a development stimulus or conservation intervention in one place having important ramifications elsewhere (Brondizio *et al.* 2009). Learning how to cope with such variability and to identify how it can be used to leverage positive change is one of the greatest challenges and opportunities facing both the management and science of sustainable development in the Amazon and elsewhere (Brondizio *et al.* 2009; Folke *et al.* 2011).

## Challenges for governance in securing a sustainable future for the Amazon

Discussions and proposals concerning the future of the Amazon suffer from the same shortcomings as many other debates about issues of sustainability – they are often catch-all, lack clarity of purpose and local relevance, and are underpinned by levels of ambition and understanding that vary enormously depending on the group of actors concerned. The enduring legacy of the Brundtland Commission (1987) is that intergenerational equity lies at the heart of the goal of sustainable development – that is, development that can meet the needs of the present without compromising the ability of future generations to meet their own needs. Holling (2001) subsequently recast this overarching goal as the need to foster and maintain adaptive capacities whilst continuing to create new opportunities for continuing development. Faced with an unprecedented state of social and ecological transition, including widespread environmental degradation and social inequality, the challenge lies in identifying, protecting and restoring the social, environmental and economic values that support this adaptive capacity, and whose loss or degradation may be irreversible or extremely costly to restore. Aspects of this overarching goal are evident in some visions of development for the Amazon region, including the Brazilian government's Plano Amazônia Sustentável, which has a strong emphasis on promoting economic betterment and reduction of poverty, whilst respecting and ensuring compatibility with social and ecological values (Federal Republic of Brazil 2008).

At a broad level we already know the main elements of a combined strategy that is needed to set the Amazon on a more sustainable trajectory (Nepstad *et al.* 2009, 2011; Malhi *et al.* 2007; Trivedi *et al.* 2009; Davidson *et al.* 2012; Boyd (7.2)). These include the need to:

- limit deforestation beneath the threshold of 30–40 per cent losses that may precipitate basin-wide shifts in precipitation through reduced transpiration and accelerated climate change;
- strengthen and expand protected areas close to the deforestation frontier;
- deliver effective state- and municipality-level planning processes to facilitate sustainable intensification of agriculture, responsible forest management, and the protection of biological corridors across already degraded landscapes;
- support a shift towards fire-free livelihoods amongst Amazonian farmers, especially the approximately 400,000 smallholders that currently lack access to technology and resources;
- alongside efforts to promote sustainable management systems, invest in increasing the value of raw agricultural and forestry products using locally trained labour forces;
- expand the agricultural land that is responsibly managed through development of reliable and premium markets, including a diversification of opportunities for the use of degraded land (e.g. silviculture and biofuels);
- support the development of stronger community-led institutions that help build adaptive capacity locally and help plan for and adapt to change (Boyd (7.2));
- effectively leverage new finance from carbon markets and other forms of ecosystem service payments to help support all of the above.

Implementing this integrated set of proposals depends upon the consolidation and scaling up of successful pilot initiatives, and the maintenance

Tipping Points-00-p.qxd 4/4/13 10:48 Page 137



of momentum against a backdrop of increasing human population and consumption, shifting market prices and the impacts of rising economic globalization, and unproven incentive systems and regulatory frameworks. There is no 'one size fits all' model. The types of governance responses that are needed to foster social and ecological sustainability vary depending on the location, the current social and ecological condition of the system, and the timescale of the specific set of problems being addressed. In presenting the concept of ecosystem stewardship as a framework for promoting sustainability in a rapidly changing planet, Chapin *et al.* (2010) identify three different levels of engagement or strategies that are necessary for developing a more nuanced and regionally appropriate set of policy approaches and incentives, namely: reduce vulnerability to risks, invest in resilience, and promote positive transformation.

The first challenge is to reduce vulnerability towards known risks. Given sufficient political will and resources, risk avoidance is relatively straightforward, as has been demonstrated by the expansion of the protected-areas system and the role this has played in lowering rates of deforestation in the Brazilian Amazon (Soares-Filho *et al.* 2010).

The second challenge is to invest in proactive policies that can improve the resilience of desirable system properties (e.g. ecologically viable forest reserves in agricultural landscapes) in the face of ongoing change. This is much harder than simply reacting to observed problems and it requires maintaining and/or restoring a diversity of options (e.g. migration corridors for biodiversity, different farm management systems and approaches to capacity building and rural extension), enhancing social learning to facilitate adaptation (including transparent information systems, effective channels of communication across different levels of government), and building adaptive governance systems that provide insurance for policy implementation by not concentrating skills and resources inside specific, overburdened institutions. Undermining efforts towards achieving these goals in the Amazon, as elsewhere, is a common lack of awareness and capacity for dealing with the often bewilderingly fast and patchily implemented changes in legal regulations, and rapid changes in market and financial incentives that influence land use choices. The continuing revision of the Brazilian Forest Code, and the growth industry of international, governmental, and non-governmental initiatives relating to the UN policy of Reducing Emissions from Deforestation and Forest Degradation (REDD+) are two such examples. The asymmetries in capacity and understanding that emerge following these changes can lead to unjust

Tipping Points-00-p.qxd 4/4/13 10:48 Page 138



biases in the distribution of both penalties and benefits, and a divergence in abilities of different stakeholder groups to respond to new threats and opportunities.

The biggest challenge for sustainability lies in transforming areas that have already undergone major changes, and which have achieved a high level of resilience around a maladaptive and inflexible system (Steffen *et al.* 2011; Boyd (7.2)). Berardi *et al.* (2011) suggest that an overemphasis on improvements in agricultural efficiency has already undermined adaptive capacity and led to such a trap in the US mechanized farming systems, with a loss of diversity in types of production and an inability to respond to unexpected shocks (such as hurricane Katrina). Achieving genuine transformation to a new development pathway is both difficult and not without risk. Plausible and desirable alternative trajectories or scenarios need to be identified, as well as potential barriers to change. Approaches need to be developed for navigating and consolidating the transitional processes that maintain broad stakeholder participation and support, as well as for building sufficient resilience to ensure the viability of the new system state.

One early attempt to promote a social-ecological transformation in the Brazilian Amazon was through the 'payment for ecosystem service' scheme, Proambiente (Programme for the Socio-Environmental Development of Rural Family Production) (Hall 2008). Under the scheme, smallholder farmers

> would cease to be regarded merely as suppliers of primary produce but be valued for their multi-functional contributions to economic production, social inclusion and preservation of the environment . . . [facilitating] compensation for environmental services rendered to Brazil and the world.
>
> (Proambiente 2003: 2–6)

Specific environmental services in this context were defined as: (1) reduction or avoidance of deforestation; (2) carbon sequestration; (3) recuperation of ecosystem hydrological functions; (4) soil conservation; (5) preservation of biodiversity; and (6) reduction of forest fire risks (Hall 2008). Despite its admirable aims, Proambiente has thus far fallen short of expectations, being undermined in particular by the lack of a national legal framework to allow direct payment schemes, but also due to limited funding, reduced implementation capacity, poor cross-sector collaboration and incompatibility with existing regional development policies (Hall 2008).

By contrast, the Municipio Verde (Green County) initiative spearheaded by the municipality of Paragominas in the Brazilian Amazon has achieved

Tipping Points-00-p.qxd 4/4/13 10:48 Page 139



more success in facilitating what may be seen as the start of a genuine social-ecological transformation (Guimarães *et al.* 2011).

Until the 1990s, Paragominas was a region of the Amazon notorious for lawlessness and land speculation, with rampant forest clearance and unregulated timber extraction. Following a change in local governance and the leadership of the farmers' union a key group of actors managed to turn a potential crisis situation (exclusion from access to rural credit due to high levels of past deforestation) into a positive news story (zero-deforestation pact and widespread voluntary registration of rural properties in the state environmental land register) with an associated growth in opportunities for rural development (including preferential investment by donors interested in supporting sustainability initiatives, including the Fundo Amazônia and Fundo Vale).

Nevertheless, much work remains to be completed. The majority of smallholder farmers have benefited little from the changes thus far, extensive low-yielding cattle farming still dominates much of the region, and remaining forests are highly degraded and vulnerable to continued threats from unsustainable logging and rampant fires in the dry season. It is also not yet clear how easily the relative success of Paragominas can be replicated to neighbouring municipalities that have much weaker political leadership, and still exhibit high levels of deforestation and degradation.

Ultimately the challenge of achieving sustainability in the Amazon requires engaging with problems across all three of these levels, and working to reduce vulnerabilities and building resilience within a broader agenda of transformation towards a more sustainable social-ecological system. As always, sustainability, and sustainable development, should not be seen as a static blueprint for management action but as a mechanism for creating a continued sense of purpose, and a guiding vision for social and political discourse that can balance national and regional goals with local values and circumstances. Whilst it is all too easy to become paralysed by the complexity of the challenges that confront development in the Amazon it is important to resist oversimplification of both problems and management responses.

Perhaps the most common shortcoming of proposals to better protect vulnerable ecosystems by changing institutional rules of use and sets of incentives (e.g. REDD+) is that they frequently focus on one level of governance (Brondizio *et al.* 2009; Brondizio and Moran 2012). In the case of the Amazon this is often at the basin-wide scale. This can be of limited practical value as we have a poor understanding of the wider system, and

Tipping Points-00-p.qxd 4/4/13 10:48 Page 140



the agency of most organizations and institutions to foster real change is at sub-regional, municipality, and community scales. A common response to policy failure has been to simplify governance boundaries and shift management responsibilities to higher or lower levels of public authority (Brondizio *et al.* 2009). However, higher level management can be undermined by ignorance amongst managers who are distant from the source of the problem, whilst local managers are often unaware of wider-scale connections, dependencies, and the long-term implications of their choices. The frequent disconnect and tension between state-level ecological-economic zoning processes and property-level regulations for environmental protection in Brazil is a good example of this imbalance.

Counteracting this problem of scale is not trivial and requires improving the capacity of state and local governments, and developing institutions that reach across multiple scales and actor groups (Perz *et al.* 2008; Brondizio *et al.* 2009; Boyd (7.2)). The emergence of the Governors' Climate and Forests Task Force (http://www.gcftaskforce.org/) – a multi-jurisdictional collaborative effort between states and provinces across the tropics and the USA to develop capabilities necessary for implementing the REDD+ programme – is a good example of improvements in cross-scale governance where significant progress has been made to strengthen the position of state-level actors in international forest policy. More such examples are needed at the sub-national level within Amazonian nations. The combination of state and non-state actors in such hybrid governance models can help reconfigure state–market–society relationships towards improved social and environmental outcomes (Brannstrom *et al.* 2012). However, a lot of care is needed to ensure that responsibilities and capacities are not excessively transferred to large non-governmental organizations which may in turn lead to unsustainable and politically unviable institutional dependencies.

## Challenges for science in securing a sustainable future for the Amazon

Science has a critical role to play in developing and securing a transition towards a more sustainable future for the Amazon region. Whilst an impressive body of knowledge has already been generated (Barlow *et al.* 2010; Davidson *et al.* 2012), the scientific community is commonly criticized for failing to deliver the evidence that is most needed to foster this change.

Tipping Points-00-p.qxd 4/4/13 10:48 Page 141



A lot of applied research is often of a narrow disciplinary focus, addresses only a limited range of spatial scales, and is concerned largely with drawing attention to problems instead of developing and testing specific management and policy solutions (e.g. Ferreira *et al.* 2012). Renewed efforts are needed to develop a genuinely interdisciplinary science that can overcome these shortcomings and help steer the region on to a more sustainable pathway (Barlow *et al.* 2010; Perz *et al.* 2010b).

Social-ecological research in the Amazon, as elsewhere, has often failed to focus on the most relevant spatial scales for guiding the development of more sustainable land use strategies. Instead, a lot of work has been concentrated either on the entire Amazon basin, thereby obscuring important inter- and intra-regional processes and interactions (Brondizio and Moran 2012), or on a detailed understanding of a small number of well-known research sites, thereby capturing only a tiny fraction of the variability in key environmental and land use gradients that drive social and ecological change (e.g. as in the case of biodiversity research; Peres *et al.* 2010). Whilst both large- and small-scale research is necessary, much more work is needed at the mesoscale (i.e. 100s km). Perhaps most importantly, the mesoscale corresponds to the scale of municipalities or counties – the administrative unit which resonates most closely with local pressures on natural resources and social services, as well as being responsible for institutional linkages between local communities and regions or states (Brondizio and Moran 2012). In addition, focusing work at the mesoscale allows for a more meaningful cross-scale or nested analysis that can simultaneously draw on data and understanding regarding both local and regional processes in a way that research focused at either the smallest or largest scales cannot readily achieve.

Building effective interdisciplinary research programmes remains one of the most difficult challenges facing the development of sustainability science (Carpenter *et al.* 2009). In summarizing the status of scientific knowledge across fourteen different areas of research in the Amazon, Barlow *et al.* (2010) emphasize the benefits of a shared geographic focus in developing a more interactive and interdisciplinary research and learning environment. Indeed, accelerating the acquisition of reliable and contextualized knowledge about the fate of the Amazon is partly dependent on our ability to build research networks that can effectively exploit economies of scale in shared resources and technical expertise, recognize and make explicit interconnections and feedbacks among sub-disciplines, and increase the temporal and spatial scale of existing studies. Researchers also need to conceptualize interdisciplinary research as being much more than a combination of different sets of skills and data, and rather an opportunity to compare and integrate what are often fundamentally different ways of thinking (Polasky *et al.* 2011).

Ultimately the success of any such research network depends on the active participation of local and regional stakeholders, alongside different scientific disciplines, in a co-designed approach to research and implementation (Future Earth 2012). Managing such networks is challenging, and requires capabilities and strategies that often go far beyond the remit of normal scientific training, including managing the politics of collaboration and cooperation and building functional redundancies across networks in order to withstand the possible loss of key individuals or institutions.

## Conclusions

The introductory chapter of this book (1.1) expanded the tipping point metaphor beyond thinking about threshold shifts in a system state to a much broader heuristic device for conceptualizing the causes and consequences of unprecedented change across multiple social and ecological attributes. In doing so it urges both decision makers and scientists to be more imaginative in seeking to understand and address the challenges that face the development of more sustainable and socially progressive economies. The editors of this volume further propose that human societies are predisposed towards creating the conditions that may contribute towards tipping points in physical and social conditions, and also that efforts to adapt to such changes can often have an exacerbating effect. Some evidence of both propositions can be found in the Amazon which, in only a few decades, has undergone an unprecedented period of social and ecological change and disruption. The spectre of a clearly defined tipping point in the Amazon system, driven by a threshold change in regional deforestation and/or global temperature increases, remains poorly understood due to variability in predicted climate and land use changes as well as ecosystem responses. Nevertheless, and despite recent positive changes – including a dramatic reduction in the rate of deforestation in Brazil – the region currently stands at a crossroads, with the long-term integrity of Amazon forests threatened by positive feedbacks between land use and climate change that could lead to a widespread shift towards an impoverished and fire-prone setting.

Tipping Points-00-p.qxd 4/4/13 10:48 Page 143



On a more positive note the editors also urged us all to think about the possibility of positive transformational tipping points where societal responses can turnaround trajectories of degradation and maladaptation to build institutions that are capable of restoring and maintaining sustainable social-ecological systems. It is reassuring to observe that, while far from dominant or secure, elements of this potential for transformation are emerging across the Amazon in the form of declining deforestation rates, changing land use practices, and the emergence of a critical mass of individuals and institutions committed to demonstrating the potential for positive change (Hecht 2011). Building upon and consolidating these changes ultimately requires adaptability in the responses of decision makers at all levels of governance, and the support of a solution-orientated and interactive scientific community.

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