ISSN: 0959-3780

Can the global environment sustain the increasing world consumption of beef? A synthesis of case studies from Queensland, Colombia and Brazil.

Authors: C.A. McAlpine[1], A. Etter[2], W.F. Laurance[3], L. Seabrook[1], S. Heyenga[4], P.M. Fearnside[5]

1. Centre for Remote Sensing and Spatial Information Science, School of Geography, Planning and Architecture, The University of Queensland, Brisbane, Australia 4072.
2. Department of Ecology and Territory, Javeriana University, Bogotá, Colombia
3. Smithsonian Tropical Research Institute, Apartado 0843-03092, Balboa, Ancón, Republic of Panama
4. CSIRO Sustainable Ecosystems, Bioscience Precinct, St Lucia, Brisbane 4072.5. National Institute for Research in the Amazon (INPA), C.P. 478, CEP 69.011-970, Manaus, Amazonas, Brazil

Author for Correspondence:
Dr. Clive McAlpine
Phone: +61-7-336-56620
Fax: +61-7-336-56899
Email: c.mcalpine@uq.edu.au

Keywords: beef consumption, carbon credits, deforestation, ecosystem degradation, exotic grasses, greenhouse gases, market forces, new consumers, regrowth forests, soya beans

Running title: Cattle and global change

Abstract

Can the global environment sustain an increasing world consumption of beef? We provide a comparative analysis and synthesis of the expansion of beef cattle production and its regional and global environmental impacts for Queensland (Australia), Colombia and Brazil. Evidence assembled indicates that rising beef consumption is a major driver of regional and global change, and warrants greater policy attention. We propose four policy imperatives to help mitigate escalating environmental impacts of beef: stop subsidising beef production and promoting beef consumption; control future expansion of soybeans and extensive grazing; protect and restore regrowth forests; and allocate resources to less ecologically damaging alternative land uses.

1. Introduction

The impact of humans on the global environment is unprecedented (Vitousek et al., 1997; Foley et al., 2005; Lambin et al., 2006; IPCC, 2007a). Global climate change, deforestation, dwindling water resources, desertification and loss of biodiversity are all symptoms of human-accelerated environmental change. These pressures stem from human population growth, and the rapidly expanding level of per capita consumption (Myers and Kent, 2004). While population growth rates in developed countries are declining, they continue to grow at rapid rates in many developing countries such as in Latin America, India and South East Asia (United Nations Secretariat, 2007). Growth in per capita consumption since the 1980s is prevalent in developed countries and increasingly so through the emergence of 'new consumers', estimated at over one billion people, in the affluent middle class of rapidly developing regions such as China, India and Latin America. The demand of these new consumers for motor vehicles, energy, household goods and meat-rich diets is increasing the pressures on ecosystems around the globe (Myers and Kent, 2004). The challenge of the 21st century is for socio-economic systems, including consumption behaviours of both developed and new consumer societies to become more sustainable in response to potentially catastrophic global environmental change.

While the world is becoming increasingly carbon-conscious (Stern, 2006; IPCC, 2007a, b), a parallel but equally important issue is the impact on the biosphere due to population growth and increased per capita consumption levels (Pielke, 2005). Ruminant meat consumption has become a status symbol of the growing affluence of the new consumer societies (FAO, 1997). World meat consumption increased from 47 million tons in 1950 to 260 million tons in 2005, more than doubling the consumption per person from 17 kg to 40 kg year^{-1} (Brown, 2006). Beef, historically linked to western culture (Rifkin, 1992), is becoming increasingly popular and/or affordable in new consumer societies such as China, Korea, Malaysia, Philippines, Indonesia, Mexico and Brazil, due to growth of personal income in those societies (Myers and Kent, 2004). Increased global demand for beef is being met from two main sources: (i) rapidly expanding feedlot production; and (ii) intensification and spatial expansion of managed grazing systems. Both have significant regional and global environmental impacts.

Feedlot production relies on grain and legume crops to feed livestock (predominantly cattle), with approximately 34% of the world's cropland now used to produce feed grains and legumes for livestock (Steinfeld et al., 2006). Keyzer et al., (2005) forecast that feedlot production will increase faster than the 1.2% per annum predicted by FAO (2002) because more people will be eating beef and so more crops will be required to feed the cattle herd. Growing crops to feed animals requires high amounts of external inputs of nutrients, water and energy (Steinfeld and Wassenaar, 2007), and has substantial environmental impacts at the regional and global scales. At the regional scale, feedlots increase demand for agricultural land and hence pressures for conversion of native ecosystems to agriculture.

Feedlots are also a significant contributor to elevated greenhouse gases Their intensive, high-input production, produce nearly twice the CO_2 equivalent per animal than cattle grazing pastures (Subak, 1999). The high-energy feed also increases enteric fermentation and produces large amounts of manure and urine from which methane (CH_4) and nitrous oxide (N_2O) are produced, with the proportion released into the local environment and atmosphere depending on treatment, storage and disposal methods (Steinfeld and Wassenaar, 2007). CH_4 is the second most important greenhouse gas emitted by human activities, while N_2O is an even more potent greenhouse gas (Vitousek et al., 1997; Steinfeld and Wassenaar, 2007). Soya meal is now a major input into feedlot livestock production in China, United States and Brazil (Brown, 2006).

Conversion of tropical forests and savannas for soya production is accelerating to meet the demand for feed rations for cattle and swine feedlots. In the Amazon, for example, the rapid expansion of soya production has destroyed large areas of tropical forest and *cerrado* savanna, releasing CO_2 into the atmosphere through biomass burning, and displacing many small farmers and ranchers, forcing them ever further into frontier areas (Fearnside, 2001b). Soy farmers are also a powerful political lobby in Brazil who have been instrumental in promoting major new highways and transportation projects that are having dramatic impacts on Amazonian forests (Laurance et al., 2001; Soares-Filho et al., 2004).

The increased demand for beef is also driving the spatial expansion of managed grazing lands. Managed gazing lands occupy 25% of the global land surface (Ramankutty and Foley, 1999a; Asner et al., 2004). The global cropland area increased roughly five-fold from 1700 to 1990, whereas grazing land increased by more than six-fold for the same period (Asner et al., 2004; Lambin et al., 2006). Asner et al., (2004) contend that while managed grazing is a spatially diffuse land use and less intensive than cropping, globally it is a major driver of deforestation, woody encroachment and desertification. Conversion of native forests to cattle pastures negatively impacts biodiversity, water quality and a range of ecosystem functions and services. The resulting changes in land cover and land use represent a major contributor to elevated global levels of atmospheric CO_2 (Ramankutty and Foley, 1999c), and can also can have a significant positive feedback on regional climate, further accentuating the effects of well-mixed greenhouse gases (Binning et al., 2001; DeFries and Bounoua, 2004; Dale and Polasky, 2007; Foley et al., 2007; McAlpine et al., 2007).

In Brazil, large-scale grazing is expanding into former tropical forests in the Amazon and also into the Cerrado savanna-woodlands to the south of the Amazon (Laurance et al., 2001a; Fearnside, 2005). In Colombia, extensive cattle ranching is the major driver of deforestation in the Amazon and the conversion of the Llanos savannas (Etter et al., 2006c). In Queensland (northern Australia), a global deforestation hotspot (Lepers et al., 2005), there has been broad-scale conversion of dry forests to exotic cattle pastures (McAlpine et al., 2002; Seabrook et al., 2006). Extensive grazing has also impacted the rich biodiversity of Australia's tropical savannas, the world's largest intact savanna biome (Woinarski et al., 2007). In both South America and northern Australia, the conversion of native forests has the greatest environmental impact, with the grazing of intact savanna ecosystems having a less intensive but still significant environmental impact. It is important therefore to recognise the contribution of extensive grazing and extensive feedlots as a major driver of regional and global change. It is therefore timely to question the role of increasing world consumption of beef as a driver of regional and global environmental change, and to identify appropriate policy responses to reduce these impacts.

The paper aims to raise international policy awareness of the magnitude and severity of the regional and global environmental impacts of the increasing world consumption of beef by providing evidence from three case study regions: Queensland (Australia), Colombia and Brazil. The case studies were selected because beef production and fodder crops (especially in Brazil) are major drivers of land-use/land-cover change (LULCC) in each region. The regions (especially Queensland and Brazil) possess extensive peer-reviewed evidence of the environmental impacts of beef production. Queensland is a major international exporter of beef products and has recently introduced polices to control land cover change, mainly for increasing the productivity of cattle pastures. Colombia has a large cattle herd with a long history of cattle as a driver of LULCC. Brazil has the world's largest cattle herd and is a major exporter of beef and soybeans. We draw on this evidence to detail the extent of LULCC, the resulting impacts on biodiversity, loss of ecosystem integrity through the introduction of invasive exotic grasses, water supply functions, and soil health. We also assemble evidence of the contribution of beef production to regional and global climate change. Based on this evidence, we then highlight key policy imperatives for addressing the environmental impacts of increasing global consumption of beef.

The paper is structured into three sections. The first section outlines a theoretical framework of the key processes and feedbacks of beef consumption on the regional and global environment. The second section reviews the historical drivers of the expansion of the cattle production (both extensive grazing and feedlot production) and the regional and global environmental impacts. Within the overarching concept of LULCC, we detail how beef production drives tropical and sub-tropical deforestation and conversion of savanna ecosystems. The primary focus is on deforestation and its consequences for biodiversity and ecosystem function. The conversion of savanna ecosystems and resulting environmental impacts is a secondary focus. In the final section, we present a comparative synthesis of the case studies, outlining key policy imperatives for addressing regional and global environmental issues.

2. Theoretical framework

The expansion of the beef cattle industry is driven by a series of interconnected socio-economic factors, often encouraged by government policy (Fig. 1). While per-capita beef consumption remains high in developed countries, the major contemporary driver is the emergence of an affluent middle-class in many developing countries. The use of cattle to secure land tenure is a perverse socio-economic driver of colonisation frontiers in Latin America. Production of beef and fodder crops such as soybeans also represents an important income source for farmers and a significant export income for some countries.

INSERT FIG. 1. HERE

The growing demand for beef is met by the geographic expansion of managed grazing lands and the intensification of production through the use of feedlots (Fig. 1). This expansion and intensification drives LULCC especially in tropical and sub-tropical regions, which disrupts the complex interactions of ecosystem services provided by the biosphere, including maintenance of biodiversity, water quality services, renewal of soil fertility, and partial stabilisation of climate (Daily, 1997). Changes in climate attributable to LULCC are both biophysical (i.e., changes in water, energy or momentum balance), referred to by Foley et al. (2003) as the green surprise, and biogeochemical through changes in the proportion of important trace gases such as CO_2 and CH_4 in the atmosphere. Beef cattle also contribute directly to biogeochemical changes in atmospheric composition through enteric fermentation (CH_4) and manure production (N_2O). The framework highlights key areas where opportunities for policy intervention may be targeted to mitigate and ameliorate the negative impacts of beef production on the regional and global environment (shaded boxes in Figure 1). These include: reducing demand for beef, limiting deforestation and conversion of savannas for beef production and soya plantations, and allocating resources to less damaging methods of beef production or alternative land uses.

3. Queensland Case Study

3.1. History and drivers

The impacts of pastoral and agricultural development since European settlement (1788) have permanently changed the Australian environment (Hobbs and Hopkins, 1990). Beef production is now the most common enterprise on Australian farms, with nearly half of all agricultural establishments having some beef cattle. The beef cattle herd is concentrated in the states of New South Wales and Queensland, with 40-45% of the Australian herd in Queensland. The social and economic development of Queensland has been closely tied to cattle and sheep, with cattle initially grazing native grasslands and woodlands not suitable for sheep. Over the past 50 years, sheep numbers have declined while the cattle herd has nearly doubled, reaching 11.5 million in 2004 (Fig. 2a). Managed grazing occurs over 81% of the state with 45% of farms specialising in beef (Australian Bureau of Statistics, 2006). The recent expansion in cattle numbers has been partly due to rising cattle prices (Fig. 2b), the cross breeding of European (*Bos taurus*) and Brahman (*Bos indicus*) cattle, the latter being more suited to sub-tropical and tropical conditions. The cattle increase has also been partly due to the higher productivity of exotic pastures planted on land cleared of native forest. A large proportion of Queensland's beef production is exported, with beef exports valued at AUD2.8 billion (8% of value of Queensland exports) in 2005-2006. The main export markets in 2001 were Japan (48%), USA (31%), Korea (5%), Canada (4%) and Taiwan (3%), with a smaller live cattle trade to Indonesia, Malaysia and the Philippines.

INSERT FIG. 2. HERE

3.2. Land use and land cover changes

The Queensland landscape has undergone steady transformation since European settlement, with deforestation accelerating since the 1960s. Since 1988, when satellite monitoring of woody vegetation commenced, clearing has occurred at a rate varying between 300,000 – 700,000 ha year^{-1}, the majority of which was for improved cattle pastures (Fig. 2b). Deforestation has been concentrated in central and southern regions where native forests and woodlands on fertile clay vertisols have been converted to intensive cropping and exotic pastures. A combination of fertile soils, high cattle prices and adequate annual rainfall (500 – 750 mm) has made clearing a viable economic proposition in these regions, at least in the medium term (Rolfe, 2002). However, the rate of deforestation is not directly correlated with the price of beef (Fig. 2b), with drought and cattle farmer response to impending government vegetation management policy also being important influences. Many eucalypt and acacia ecosystems have the capacity to regenerate naturally through vegetative means, commonly referred to as regrowth (McAlpine et al., 2002; Seabrook et al., 2006). Clearing is less widespread in northern regions, where grazing occurs on native grasslands and savanna woodlands where there is lower economic benefit from clearing.

Over the past decades, crop production in Queensland, as in the rest of Australia, is increasingly directed towards livestock feed to increase productivity and to supplement grazing during drought. In 2005-06, 1.5 million beef cattle were fed 1.18 million tons of feed grain, with 79% being met by Queensland production. The main grains fed to cattle were sorghum (38.5%), wheat (33.2%) and barley (24.4%). Soy meal is not commonly fed to cattle in Queensland. In

2005, grain sorghum occupied 20% of cropped land, with a further 19% used for feed grain production of wheat and barley. Hay from pasture and other crops occupied a further 4%.

3.3. Regional environmental impacts

The contemporary expansion of the beef cattle industry in Queensland has resulted in the extensive loss and fragmentation of native forests (Fig. 3), replacing them with exotic pastures such as the highly productive but also highly invasive buffel grass (*Cenchrus ciliaris*), introduced from Africa. The most fertile soils have less than 10% native vegetation cover, often occurring as linear remnants in a grazing matrix (McAlpine et al., 2002). Woody regrowth can form an important component of the matrix, providing opportunities for passive landscape restoration (Bowen et al., 2007). Conversion of native forests to cattle pastures has undoubtedly incurred a significant biodiversity extinction debt, the full impact of which will not become apparent for 50-100 years (McAlpine et al., 2002).

Habitat loss and fragmentation forces native birds, reptiles and mammals that survive into remnants where they either become easy prey of feral cats and foxes or their numbers fall below a viable threshold (e.g. Ludwig et al., 2000; Hannah et al., 2007). In the highly fragmented Brigalow Belt bioregion, reptile populations have undergone major declines (Covacevich et al., 1998). The majority of native fauna species are adversely affected by grazing, with only a few benefiting from grazing (Woinarski and Ash, 2002). Floristic diversity has also been greatly reduced (Fairfax and Fensham, 2000), with remnants in the proximity of improved pasture particularly prone to invasion by exotic grasses such as green panic (*Panicum maximum*) and buffel grass resulting in intense fires that accelerate remnant degradation and loss of floristic biodiversity (Butler and Fairfax, 2003). Grazing, together with changes in fire regimes, also has proved to have a significant effect on species composition in savanna woodlands (Crowley and Garnett, 1998; Sharp and Whittaker, 2003).

There is also growing evidence that deforestation in Queensland and other regions of Australia is impacting the regional climate, resulting in warmer and drier conditions (McAlpine et al., 2007). This raises important questions about the clearing of native forests and woodlands for cattle pastures exacerbating the impact of drought on Australia's natural resources and ecosystems, and highlights a strong feedback effect between deforestation and a drying trend in cleared regions, but also teleconnecting to regions remote from where the clearing occurred.

INSERT FIG. 3. HERE

3.4. Global environmental impacts

The beef cattle industry contributes significantly to Queensland's greenhouse gas emissions. In 2004, methane emissions from enteric fermentation were calculated at 1.03 million tonnes, the equivalent of 22.8 million tonnes of CO_2 or 14% of all greenhouse emissions in Queensland (Australian Greenhouse Office, 2006). Deforestation (Fig. 3) contributed a further 18% of Queensland's greenhouse gas emissions. Cropped land is also a net source of greenhouse gas, with net emissions from agricultural soils amounting to 3.6 million tonnes of CO_2 in 2004. Grazing pressure also affects the soil carbon stocks through loss of perennial grass cover (Henry et al., 2002). Different grazing management options therefore can increase sink potential of grazed lands but most often the sink increase comes from reducing grazing pressure and regrowth of trees (Howden et al., 1994; Howden et al., 2001; Chen et al., 2003). Regrowth of previously cleared forests and vegetation thickening of remnant forests and woodlands contributes to mitigating greenhouse gas emissions associated with the cattle industry by increasing absorption of CO_2 (Gifford and Howden, 2001; Henry et al., 2002).

3.5. Policy responses

For most of Queensland's pastoral history, land clearing was a condition of pastoral leases. However, in response to international and national concerns over loss of biodiversity and greenhouse gas emissions, from the mid-1990s the Queensland government progressively introduced more stringent legislative controls over deforestation. Under the Vegetation Management Act of 1999, as amended in 2004 (Queensland Government, 2004), broadscale clearing of remnant (structurally intact) native vegetation was no longer permitted in rural areas, although recent regrowth may be cleared and permits are issued for cutting some leguminous acacia species to feed livestock. Despite the introduction of legislative controls, illegal clearing of remnant vegetation continues to occur. The beef cattle industry has reacted negatively to this legislation, with the full effect on the industry and the environment yet to be realised.

4. Colombian Case Study

4.1. History and drivers

Cattle have also played an important role in transforming Colombian landscapes since their introduction in the early 1500s (Fig. 4). This long-lasting impact on Colombian ecosystems continues to date, with the expansion of cattle grazing in frontier regions such as the Amazon and Magdalena (Etter et al., 2008). Although the main motivation in the early colonization of Colombia, as elsewhere in Latin America, was the plundering and mining of gold and emeralds, cattle, sheep and horses were very important in the gradual occupation and control of indigenous lands (Melo, 1998). From early stages of colonialism, cattle steadily expanded into the Orinoco and Caribbean natural savanna grasslands, or converted dry tropical forest vegetation types in the inter-Andean valleys and the Caribbean. Since 1920, the size of the national cattle herd has increased exponentially (Fig. 4). The current cattle herd is around 27 million head, mostly concentrated in the Andean and Caribbean regions. However, the present-day cattle industry is economically inefficient in most regions, with 75-80% of production costs being on-farm costs (Rosas and Perry, 2002). Domestic consumption is relatively low, with around 3 million head year^{-1}, or about one head per 15 inhabitants. Recent studies show that beef consumption in Colombia has dropped from 21 kg in 1990 to 16 kg per capita in 2002, whereas the average for Latin America was 25 kg (Rosas and Perry, 2002). Traditionally there has been a flow of live cattle to Venezuela. During the late 20th century, Colombian beef was banned from the US and Central America due to foot-and-mouth disease problems. From 2000 however, the control of foot-and-mouth disease in most regions has made the export of Colombian beef possible.

INSERT FIG. 4. HERE

4.2. Land use and land cover changes

From 1850 there was an increase and intensification of agricultural production, paralleled by an increase in cattle production due to the introduction of wired fencing and exotic pastures (Ocampo, 1987; Yepes, 2001) (Fig. 4). During this period, the cattle industry benefited from the introduction of African grasses, such as kikuyo (*Pennisetum clandestinum*) in the Andean highlands, gordura (*Melinis minutiflora*) and puntero (*Hyparrhenia rufa*) in the lowlands.

Thereafter, the pressure of the cattle industry on the environment continued to increase, with the herd size growing nearly threefold, reaching 14.5 million head by 1970. The area under exotic grasslands continued to increase with the introduction of brachiaria grasses (*Brachiaria spp.*) in the early 1970s in the lowlands and lower-Andean belt. Currently agricultural lands under introduced and native pastures account for about 90% of the country's agricultural area (Fig. 5). Deforestation is currently occurring at a rapid rate in the lowlands of the Amazon and Pacific regions and the foothills of the Andes (Etter et al., 2006c). Since 1990, increasingly large areas of natural savannas are being converted to introduced pastures and crops. The main driver of such land-cover changes is the cattle industry. Intensive feedlot cattle production is not yet a practice in Colombia as it is in Australia or the United States, but may occur if the markets trigger increased demands of beef for export in the future.

INSERT FIG. 5. HERE

4.3. Regional environmental impacts

The process of deforestation and agricultural expansion into the forested ecosystems has characteristically led to landscapes almost devoid of the natural forest vegetation, generally with less than 10% of the original cover (Etter et al., 2006b), with resulting high impacts on biodiversity (Chaves and Arango, 1998; Chaves and Santamaría, 2006). By 2000, 40 million ha of native vegetation had been cleared in Colombia (Fig. 5) (Etter et al., 2006c), mostly forest ecosystems renowned as biodiversity hotspots such as the Andes and northwest Amazon (Dinerstein et al., 1995; Chaves and Arango, 1998). Clearing, predominantly attributable to cattle grazing, has had a significant biodiversity toll (Etter et al., 2006c). However, to date there are no reliable national estimates on the rates of land clearing for Colombia due to the lack of a national monitoring system and the unavailability of cloud free satellite images. Current annual clearing rates are estimated at between 150,000 and 250,000 ha of forests and some 50,000 ha of savannas, mostly for cattle grazing (A. Etter unpublished data).

Deforestation is currently concentrated in the tropical lowlands (Etter et al., 2006a; Etter et al., 2006c). Large areas of economically less-suitable agricultural lands increasingly being devoted to cattle grazing concentrated in large holdings (Yepes, 2001), while smaller areas of more marginal land are slowly being abandoned and left to regenerate, such as in the Chicamocha region (Cárdenas, 2000; Etter and Villa, 2000). In the mountainous Andean regions where deforestation occurs on steep slopes, grazing can significantly contribute to soil erosion processes. Unfortunately, there is currently little research quantifying these effects (Chaves and Santamaría, 2006). A major environmental impact of cattle grazing in Colombia has been the introduction and spread of exotic grasses, such as kikuyu above 1500 m in the Andean region, and brachiaria in the humid lowlands and gordura in the drier areas below 1500 m. These exotic grasses cover most cleared forest areas now under grazing in the sub-humid to humid areas, degrading native biodiversity and ecosystem processes by outcompeting natural grasses, changing fire regimes and inhibiting tree regeneration (Williams and Baruch, 2000; Mistry and Berardi, 2005; Hoffmann and Haridasan, 2008). In savannas of the Orinoco and Caribbean regions, exotic grasses have historically been planted to improve forage quality.

The cattle industry is also an important driver of land concentration and social conflicts (Hecht, 1993; Yepes, 2001). In the Colombian Amazon, the livestock sector is closely related to most other rural development activities, making it a powerful driver of social change. Colonist farms mostly include cattle because they provide a reliable cash source. As in the Brazilian Amazon, cattle ranching in Colombia has been a means of claiming and controlling land and obtaining tax exemptions, subsidies, cheap credit and speculative gains (Yepes, 2001). In

Colombia, cattle ranching has often been a tenuous economic activity that relies on large scale extensive use of the land. Most transfers of public lands to private ownership in Colombia have been through illegal invasions, which are later legalised and secured as grazing land use, practices that also occur in Brazil. Unlike Queensland, the Colombian cattle industry has not contributed substantially to the economic and social development of the country.

4.4. Global environmental impacts

According to data from the Intergovernmental Panel on Climate Change (IPCC), agriculture and land-use change in Colombia contributed 50% of the national carbon dioxide (CO_2) emissions (85.2 Tg per year CO_2 eq.) (IDEAM, 2008). The cattle industry impacts climate through emissions of CO_2 and trace gases such as methane (CH_4) and nitrous oxide (N_2O) from deforestation and from trace-gas emissions by savanna fires and from enteric fermentation in cattle. Deforestation in the Colombian Amazon alone is estimated to contribute 13.5 million tonnes of CO_2 per year (IDEAM, 2008). Some 20 million hectares of savannas are grazed, of which an estimated 7-15% are burned every year; this periodic burning emits around 14.5 million tonnes CO_2 $year^{-1}$ (A. Etter unpublished data), but this is reabsorbed when the savanna grasses regrow. However, the trace gases produced by savanna burning do not enter photosynthesis and represent a net contribution to global warming. Not all of this trace-gas emission can be attributed to use of the savannas for grazing, as less-frequent burning also occurred prior to the introduction of cattle. The increase in the frequency of burning in recent years, however, contributes to global warming both through the emission of trace gases and by net emissions of carbon caused by drawing down carbon stocks in the woody component of the savannas. This has been found in the *lavrado* savannas of Roraima, just across the border from Colombia in Brazil (Barbosa and Feamside, 2005a; Barbosa and Fearnside, 2005b). With a cattle herd in Colombia of over 27 million head, the contribution of cattle to greenhouse gas emissions through CH_4 from enteric fermentation and manure is estimated at 55.2 million tonnes per year CO_2 equivalent (A. Etter unpublished data and figures from Boadi et al., 2004).

4.5. Policy responses

In Colombia, there has been no equivalent to the 1999 Queensland native vegetation management legislation and subsequent amendments. Historically, Colombia has adopted a low law enforcement option for the protection of the National Forest estate. The agricultural frontier has continued to expand in most regions, but especially in the humid Amazonian and Pacific lowlands (Etter et al., 2006a; Etter et al., 2006c). Most areas where the agricultural frontier is currently expanding correspond to State Forest Reserves dating from 1959 (MAVDT, 2007).

5. Brazilian Case Study

5.1. History and drivers

Cattle ranching in Brazil has tremendous environmental impacts because of its rapid advance into native vegetation. Brazil’s Atlantic forest has been nearly completely destroyed over the past five centuries, with conversion to cattle pastures the dominant driver since 1950. The biologically diverse but poorly protected *cerrado* savannas of central Brazil have been undergoing rapid transformation to exotic cattle pastures and more recently to soybeans. Exotic planted pastures are also replacing other Brazilian savannas, such the pampas of Rio Grande do Sul, the *pantanal* wetlands and the *lavrado* savannas in Roraima in the far northern portion of Brazilian Amazonia.

In Amazonia, the historical role of cattle ranching in deforestation is partly a result of the favourable tax and credit incentives received by cattle ranchers from the mid-1960s through mid-1980s which made converting forest to pasture more profitable than the sustainable use of already-cleared lands (Hecht, 1993; Moran, 1993). However, even at the height of the government incentives programs in 1975, over 45% of all clearing in eastern Amazonia (along the Belém-Brasilía highway) was in large ranches that received no government subsidies (Fearnside, 1990). In part, this reflects the economic attractiveness of cattle ranching to Amazonian farmers and the acceptance of cattle ranching as a prestigious activity in Brazilian society (Andersen et al., 2002; Mertens et al., 2002).

Today, Brazil's cattle herd is the largest in the world, with most of the recent growth occurring in the rapidly expanding ranching operations in the Amazon (Fig. 6). The cattle herd in Brazilian Amazonia increased from about 22 million head in 1990 to 74 million head in 2007 (Kaimowitz et al., 2004; Smeraldi and May, 2008). Brazilian beef exports have risen sharply in the last decade because Brazil is largely free from foot-and-mouth disease (Laurance et al., 2005). Brazil is by far the world's largest exporter of beef, with a third of all exports now coming directly from the Amazon. In the past five years, beef exports have grown dramatically in four southern-Amazonian states, Pará, Mato Grosso, Rondônia, and Tocantins.

INSERT FIG. 6. HERE

5.2. Land use and land cover changes

Despite the growing profitability of cattle, numerous studies have emphasized that large landholders in Amazonia are generally less interested in raising cattle than in securing land tenure. Under Brazilian law, clearing land for pasture is considered an "effective use" of land and is a first step towards securing ownership (Fearnside, 2001a). Securing ownership is critical to both land speculators and to large landholders because of the threats of invasion by landless peasants or of possible expropriation under a government land-redistribution program. Cleared land is worth 5-10 times more than forested land, a profitable incentive to the owner whose ultimate goal is resale (Mertens et al., 2002). The strong performance of land prices in the face of Brazil's high rates of inflation in the 1970s and 1980s, and the fact that capital-gains taxes are almost never collected, has meant that land speculation has long been popular in Amazonia. The cheapest and most efficient way of maintaining cleared land is by cattle grazing, and the ubiquity of cattle operations with very low stocking densities in Amazonia suggests that maintaining cleared land is indeed a prime motivation for much of the recent explosion of cattle ranching (Veiga et al., 2001).

The explosion in ranching is concentrated in large and medium properties (>100 ha and often vastly larger) held by wealthy landowners. In the forests and *cerrado* woodland-savannas of Amazonia, properties over 2000 ha in size, which are almost always cattle ranches or soy farms, constitute only 1% of all agricultural establishments but contain 47% of all land converted to agriculture. In contrast, small farms less than 20 ha constitute >50% of all properties but contain only 1.5% of the land converted to agriculture (Chomitz and Thomas, 2001). Industrial soybean farming is growing rapidly, with soy farmers buying cattle ranches and converting them to soy fields, displacing the ranchers and pushing them further into the forest frontier (Fearnside, 2001b). Annual deforestation rates in the Brazilian Amazon vary from about 1-3 million ha $year^{-1}$ (Laurance et al., 2004), but averaged ~1.9 million ha $year^{-1}$ from 1978 to 2007 (using data from INPE, Brazil's National Institute for Space Research). Cattle ranching and small-scale farming have historically played the most important roles in the deforestation process in the so-called 'arc of deforestation' along the southern and eastern fringes of the Amazon Basin, with an increasing fraction of this land currently being converted to industrial soy production (Fig. 7; Fearnside 2001b). Estimated deforestation rates (derived from 20-m resolution satellite imagery from INPE) indicate an increase from 2001 through 2004 and then a decrease through July 2007, with coarse-resolution MODIS (250 m) imagery indicating a sharp rise in deforestation from August to December 2007. Beef and soy prices correlate well with the deforestation rate in the following year over the 1995-2007 period (IMAZON, unpublished data), indicating an important role of commodity prices in contemporary deforestation (Fig. 6). The effect is in addition to a series of "ulterior" motives that add profitability to ranching, including land speculation, securing timber stocks, and money laundering (Fearnside, 2008). Intensive feedlots are not yet common in Brazil, although establishment of these operations in Mato Grosso beginning in 2006 may be a harbinger of future trends.

INSERT FIG. 7. HERE

5.3. Regional environmental impacts

The environmental impacts of an expanding beef herd in Brazil are well documented (Fearnside, 1997b; Laurance et al., 2001a; Fearnside and Laurance, 2004; Fearnside, 2005). Loss of Amazon forest results in a decline of biodiversity though the reduction of forest area, especially in the case of endemic species with limited ranges (e.g., Dirzo and Raven, 2003; Millennium Ecosystem Assessment, 2003). The impact of forest loss is compounded by fragmentation and edge effects that increase in importance as the remaining forest is reduced to islands in a sea of pasture. These effects have been evidenced extensively by studies of experimentally isolated fragments at the Biological Dynamics of Forest Fragments Project in central Amazonia (e.g., Laurance et al., 1998; Laurance et al., 2002) and by studies of forest fragments left in cattle ranches in northern Mato Grosso (Peres and Michalski, 2006). The fragments suffer losses from insufficient population sizes of key species (Laurance et al., 2002) and from the hotter and drier microclimate near the forest edge (Nascimento and Laurance, 2004), the entry of fires from surrounding cattle pasture (Laurance, 2006), and from entry of secondary and exotic species (Laurance et al., 2006).

The water-supply functions of the forest are greatly diminished when deforestation occurs. Within Amazonia and in neighbouring regions, rainfall is significantly enhanced from water that is recycled through the forest. On the scale of small experimental plots, runoff increases substantially when forest is converted to cattle pasture (Fearnside, 1989; Barbosa and Fearnside, 2000). In the Tocantins Basin, which includes vast areas that have been deforested for pasture in southern Pará and northern Mato Grosso, hydrological data indicate higher annual and seasonal environmental flows than before large-scale conversion to pasture (Costa et al., 2003).

Replacement of Amazonian forest with cattle pasture has a major impact on regional and global climate. Evapotranspiration in cattle pasture is much lower than in native forest with complete deforestation reducing the region's evapotranspiration by 15-30% (Marengo, 2006). The dry season is the most critical period for maintaining rainfall within the limits of tolerance of Amazonian trees. Simulations indicate that, if the forest were entirely replaced by pasture, there would be less rain and higher temperatures (Foley et al., 2007), with a sharp decline in dry season rainfall once 40% of Amazonian forest is lost (Sampaio et al., 2007). The climatic impacts of deforestation could represent a "tipping point" in provoking self-perpetuating degradation of remaining forest, and might act synergistically with the projected increase in severity of El Niño droughts provoked by global warming (Cox et al., 2004).

5.4. Global environmental impacts

Emission of greenhouse gases is one of the major impacts of converting Amazonian forest to cattle pasture (Fearnside, 2000). Half of the dry weight of forest biomass is carbon, and the difference between the biomass of forest and pasture represents a net release to the atmosphere, while conversion to pasture provokes additional emissions from loss of soil carbon (Fearnside and Barbosa, 1998). In terms of soil carbon, Amazon forest conversion to pasture typically releases 5.4 t C/ha from the top 20 cm of soil, 7.9 t C/ha from the top 1 m, or 8.5 t C/ha from the top 8 m of soil (Fearnside and Barbosa, 1998). The carbon in the deeper soil takes longer to be released than that in the surface soil. Burning associated with deforestation also releases methane (CH_4) and nitrous oxide (N_2O), adding a further 6.3-8.5% to the impact of the CO_2 released from deforestation (updated from Fearnside, 2000, based on 100-year global warming potentials from IPCC, 2007a, and emission factors from Andreae and Merlet, 2001). The annual net emissions from deforestation, based on the 19,400 km^2 per $year^{-1}$ average deforestation rate for the 2000-2007 period, was approximately 191 million tonnes of CO_2-equivalent carbon (based on Fearnside, 2000). To this must be added the trace-gas emissions from periodic burning of exotic pastures, net emissions of trace gases from soil, and methane emitted from cattle. These impacts, taken together, are tremendously large and undoubtedly make Amazonian beef one of the most environmentally damaging food sources in the world.

5.5. Policy responses

Brazil's policy responses to deforestation have been mixed. On the one hand, the Ministry of the Environment has made a substantial effort to enforce environmental legislation. On the other hand, other branches of the government promote and subsidize ranching by building and improving highways that open up poorly accessible areas of Amazonia, and by financing ranching and associated slaughterhouses and other infrastructure with subsidized interest rates. The government also invests heavily in the elimination of foot-and-mouth disease and in convincing major importing nations, such as Russia, to accept Brazilian beef. Commodity prices continue to have a substantial influence on deforestation, with low prices contributing to low deforestation rates from 2005 to 2007. A government crackdown on illegal logging and deforestation also contributed to declining forest loss during this period.

The policy lessons of this are two-fold and seemingly contradictory. First, government deforestation-control policies are not without effect and can demonstrably reduce deforestation when applied consistently (Fearnside, 2003). The recent spurt of deforestation in late 2007 does not mean that the government should give up on controlling deforestation, but rather that it should redouble its efforts. Second, the government's ability to control deforestation is not so great that it can open new highways criss-crossing the Amazon without severely threatening the forest. The region's history shows a repeated pattern of deforestation spreading outward from newly opened highways, primarily for cattle pasture. Unfortunately, this history is still very relevant (see exchange between Laurance et al., 2001b and Silveira, 2001).:

6. Synthesis of Case Studies: Environmental, Human and Policy Dimensions

6.1. Comparison

A comparison of the three case studies shows considerable regional and global environmental impacts of extensive cattle grazing and feedlots. In each case study, extensive grazing is the major driver of regional deforestation and a significant contributor to global greenhouse gas emissions. Soy production for feedlots is also an important driver of landscape change in Brazil, but less so in Queensland, where feed grains and fodder crops are an important land use, and largely absent in Colombia. Cattle are tied strongly to socio-cultural and economic development in all regions, and to international trade in Brazil and Queensland. In the South American countries, security of land tenure is closely linked to the cattle industry, driving colonisation frontiers into new regions. In Queensland, there is no longer a colonisation frontier as land has long been allocated to either private or leasehold use, and land tenure is secure and well regulated. Common to the case studies is the loss of biodiversity and ecosystem services associated with the introduction and spread of exotic grasses to increase pasture productivity and animal live-weight gain. None of the regions has specifically recognised the full regional and global environment impacts of the cattle industry, and there is still encouragement by the respective governments to further expand or intensify beef production. In Queensland, native vegetation management legislation now prohibits all broadscale forest clearing, but this came about principally because controlling deforestation was seen as the easiest option to reduce Australia's greenhouse gas emissions. In Colombia and Brazil, there is little control on forest loss, although Brazil is attempting to enforce legislation controlling deforestation.

In response to the question of the capacity of the global environment to sustain rising beef consumption, the evidence assembled from the three case studies supports the conclusion that the global environment cannot sustain the cumulative impact of rising per capita beef consumption of the new consumers on top of the existing high consumption rates in western countries. Beef consumption levels in both developed and developing countries need to be reduced. We are not proposing that the world become vegetarian, but we suggest it is essential for policy makers to recognise and move to mitigate the growing environmental costs of beef production. Intensification is not the answer as feedlots also have high environmental costs.

The case-study evidence provided here should be considered in the wider context of policy decisions affecting regional environments and global change, including forthcoming international conventions to mitigate greenhouse-driven global climate change. The evidence should inform policy development in terms of balancing the beneficial environmental effects of reducing beef consumption against the socio-economic costs for regional communities. Within this context, we propose the following policy imperatives as priority areas for addressing the adverse regional and global impacts of increasing world beef consumption.

6.2. Imperative 1. Stop subsidising beef production and promoting beef consumption

The beef industry makes an important contribution to the regional economies of Queensland, Colombia and Brazil. However, the true regional and global environmental costs of beef production (both extensive grazing and feedlots) are not factored into the market price. Rather, government subsidies and economic incentives often explicitly promote increased production. For instance, the Brazilian government directly encouraged colonization of the Amazon Basin from the 1960s through the 1980s via transport infrastructure and economic incentives predominantly directed at extensive cattle ranching (Fearnside, 2001a), as did Queensland during the Brigalow Belt Development Scheme in the 1960s (Seabrook et al., 2006).

Examples of hidden or unaccounted costs of beef production include introduction and spread of invasive grasses and deforestation, which contributes significantly to global greenhouse gas emissions and regional climate change, and degradation of ecological services such as clean water, soil health and biodiversity (Ramankutty and Foley, 1999b; Dale and Polasky, 2007; McAlpine et al., 2007). Beef is costly in terms of the resources required to produce it. Cattle are the least efficient converters of feed to meat of domestic livestock, using 9-13 kg of feed per kg of live weight (Smil, 2002), while in California it takes 13,500 litres of water to produce one kilogram of beef (Rijsberman, 2006). Future policies to protect the environment will therefore have to introduce market pricing of beef that reflects its full environmental costs (FAO, 2006).

Consumer preferences for beef also need to change. As a high priority, regional and national government agencies need to stop promoting beef consumption in both developed and new consumer societies, many of which do not have strong traditions of eating beef. Beef consumption in developed countries, especially in Europe, has been under pressure in recent decades as bovine spongiform encephalopathy (BSE) and other human health concerns reduce consumer confidence in beef. To mitigate this decline in per-capita consumption, government agencies and the beef industry have actively promoted beef products as healthy and safe. The Australian government, for example, has a long history of trade missions promoting the consumption of Australian red meat in Asia and the Middle East (Australian Bureau of Agricultural and Resource Economics, 2007). Similar programs exist in the United States, such as the Beef Promotion and Research Act of 1985 (USDA, 1985). We argue that such industry and government agendas are not environmentally responsible as “saving and repairing the planet” becomes the new global imperative.

6.3. Imperative 2. Control future expansion of soybeans and extensive grazing to halt deforestation and savanna conversion.

The beef cattle industry has a long history of deforestation in Queensland and Colombia, and more recently in Brazil, creating a legacy of loss of biodiversity, spread of exotic grasses and legumes, degradation of land and water resources, and global warming. Steinfeld and Wassenaar (2007) estimate that global livestock production, through managed grazing and fodder crops, utilises a third of the earth’s land surface and that along the entire commodity chain, livestock contribute ~18% to anthopogenic emissions. While the power-generation sector currently contributes the highest percentage of greenhouse gas emissions (24%), deforestation, mostly for agricultural expansion, is thought to contribute around 20% of all emissions (Baumert et al., 2005; Fearnside, 2005). A further 5% is contributed by methane and nitrous oxide emissions from livestock.

While there is uncertainty in estimates of carbon stocks in tropical forests (IPCC, 2007b), the effects of tropical deforestation on greenhouse emissions are substantial (Fearnside and Laurance, 2004). Feedlots, with their intensive, high-technology management, produce nearly twice the CO_2 equivalent per animal as compared to cattle grazing in pastures (Subak, 1999). The increasing use of grain and soy meal for feedlots adds to anthropogenic greenhouse gas emissions, with nitrous oxide emissions from agricultural soils contributing a further 6% to total emissions. Based on trends over the past 50 years, Tilman et al. (2001) project that by 2050, the amount of land used for crops and pastures will increase 1.18 times to nearly 6 billion hectares. The expansion will be driven by greater food demand, including beef, arising from increased wealth and population growth (Gerbens-Leenes and Nonhebel, 2002). The bulk of expansion will be in South America and sub-Saharan Africa, through clearing of natural ecosystems (Laurance et al., 2001; Tilman et al., 2001).

Avoiding future deforestation by controlling the future expansion of the beef industry (extensive grazing and feedlots), therefore, represents a priority global-change mitigation option with the largest and most immediate impact on global carbon stocks (IPCC, 2007a). However, we agree with Betts (2008) that the effects of deforestation on all ecosystem services needs to accounted for when comparing the effects of carbon dioxide emissions from deforestation and fossil fuel burning.

Tighter controls over the expansion of the beef industry and livestock fodder crops such as soybeans represent a priority global and regional strategy to halt tropical deforestation. This would make a major contribution to reducing carbon emissions and to biodiversity conservation, maintaining ecosystem services and relatively cooler, moister climates in the deforested and adjacent regions (Betts, 2008). Policy makers have been slow to recognize this two-way link between the biosphere and the climate system (Foley et al., 2003; Pielke et al., 2007). Avoiding future deforestation through reducing the consumption of beef therefore represents a win-win scenario for carbon sequestration, protecting biodiversity and maintaining regional hydrological cycles and a wide array of other ecosystem services. Controls on deforestation need to be accompanied by tighter controls over the introduction and spread of exotic grasses by the beef industry as a priority for reducing the regional environmental impacts of cattle.

If we want to slow or reverse tropical deforestation (Lamb et al., 2005), loss of global biodiversity (Tilman et al., 2001), and substantially reduce greenhouse gas emissions (IPCC, 2007a), the global community needs to focus on the link between global beef consumption levels, trade in beef and regional and global change. This requires expanding the current global climate change agenda under the Kyoto Protocol when it is negotiated at the forthcoming United Nations Framework Convention on Climate Change Conference of the Parties, to be held in Copenhagen in 2009. One of the key factors that needs to be addressed is global beef consumption. In the face of these challenges, national policies designed to slow deforestation have had mixed success to date.

Deforestation rates remain high in Brazil and Colombia, but have been reduced in Queensland.. Queensland has successfully controlled deforestation through legislation protecting remnant old-forests (but not regrowth forests) from future clearing (Seabrook et al., 2006). This legislation is backed by a comprehensive satellite monitoring program using multi-temporal imagery that provides accurate data on deforestation, including illegal clearing. In general, developing countries such as Brazil and Colombia have comparatively less regulatory capacity to control deforestation on both private and public land. However, Brazil has an advanced satellite deforestation monitoring program (INPE, 2008). A deforestation control program in the state of Mato Grosso from 1999 to 2001 demonstrated that clearing can be curtailed when remote sensing is combined with a geo-referenced licensing system that can identify illegal clearings to target field inspections (Fearnside, 2003). However, such command-and-control measures need to be accompanied by policy reforms to address root causes of deforestation, including the role of clearing in establishing land claims (Fearnside, 2005). Colombia does not have a systematic monitoring program and lacks effective deforestation controls. Monitoring is essential, but must be backed by vigorously enforced deforestation regulations supplemented by economic incentives for alternative land uses. Otherwise, left uncontrolled, the global market for beef will continue to drive future deforestation.

6.4. *Imperative 3. Strategic protection and restoration of regrowth forests.*

Secondary or regrowth forests on either abandoned or marginal land are an important landscape element in the three case study regions. Many tropical and sub-tropical forests have the resilience to recover through natural or managed successional paths (Dunn, 2004; Lamb et al., 2005; Bowen et al., 2007). While regrowth forests may not hold a similar species richness and community composition to primary forests (Barlow et al., 2002), regrowth management at a landscape level will help restore biodiversity and other ecological services in grazing landscapes and to complement remnant old forests and protected areas. There is also considerable potential for the beef cattle industry, both small and large landholders, to financially benefit from a well designed carbon sequestration policy which includes regrowth forests. Studies of savanna grasslands in Australia indicate that better management and reduced grazing pressure can increase the carbon sink potential of these ecosystems (Howden et al., 1994). However, there is even more potential for carbon sequestration through the strategic protection of regrowth forests.

At present, carbon trading to mitigate climate change is in its establishment phase, and under the Kyoto protocol, recognition of carbon sequestration in developing countries is limited to replanted forest. However, as the IPCC's Fourth Assessment Report (AR4) recognises, "one of the most effective methods of reducing emissions is often to allow or encourage the reversion of cropland (*and exotic pastures*) to another land cover, typically one similar to native vegetation" (IPCC, 2007a, p. 308). Reducing global beef consumption can contribute to these conversions and to slowing the further expansion of cropland (*e.g*, soybeans in Brazil, sorghum in Australia) and exotic pastures, and hence reduce global greenhouse gas emissions. This is a difficult challenge but represents a win-win scenario for reducing greenhouse gas emissions and for halting the decline in biodiversity and other ecosystem services that native forests support (sensu, Lamb et al., 2005).

6.5. Imperative 4. Resources allocated to ecologically sensitive alternative land uses.

The contribution of cattle grazing to environmental problems is on a massive scale, however, Steinfeld et al. (2006) believes that the potential contribution of the beef industry to solving these problems is equally large. Reducing beef consumption has major human and socio-economic implications. It is necessary to consider: what are the appropriate policies/strategies for winding back cattle numbers and reversing their impact on the regional and global environment? And, what alternative sources of income can replace that earned from beef production?

The development of diverse and sustainable grazing systems will increase the resilience of landscape to the impacts of climate change. Environmental benefits could be achieved through the integration of grazing systems with other income sources such as carbon credits, agro-forestry, biodiversity conservation, and production of agricultural commodities for direct human consumption. Such schemes would allow beef producers to diversify their income sources, while maintaining some cattle. There is a growing body of research on establishing an economic valuation for ecosystem services (Fearnside, 1997a; Pagiola et al., 2004b; Fearnside, 2008). In Central America, a programme piloting the use of direct payments for biodiversity conservation and carbon sequestration through the adoption of silvopastoral practices, including replanting trees and establishing 'living' fences has been highly successful in reducing pasture degradation and increasing landscape connectivity, at an average cost of US$38 per ha (Pagiola et al., 2004a).

Well-constructed carbon markets offer an alternative income to landholders clearing old-growth and regrowth forests for cattle ranching and soybeans (Santilli et al., 2005; Stern, 2006; IPCC, 2007a). However, while possessing considerable promise, carbon trading schemes have proven particularly challenging to implement, even in developed countries such as Australia, due to difficulties such as leakage, non-permanence of carbon storage, establishing baselines and monitoring (Santilli et al., 2005; IPCC, 2007a). In Brazil and Colombia, cattle ranching is often the cheapest and least labour-intensive method of occupying frontier landscapes and securing tenure (Hecht, 1993; Fearnside, 2001a; Yepes, 2001). Cattle provide short-term economic advantages, including low time-demand, low price risk and limited management costs. However, Coomes et al. (2008), in a study of the economic benefits of carbon over cattle for small-scale farmers in Panama, found that carbon trading whereby farmers receive annual cash payments for maintaining existing stocks of trees is more profitable in the long-term than cattle. Overcoming the existing limitations of the Kyoto protocol and accepting forest conservation as basis for reducing carbon emission and trading promises significant opportunities for halting continued conversion of tropical and sub-tropical forests to extensive cattle grazing.

7. Conclusion

The evidence assembled from the three case studies highlights the magnitude and extent of the regional and global environmental impacts caused by the rising per capita beef consumption of the new consumers on top of the existing high consumption rates in western countries. Beef consumption levels in both developed and developing countries need to be reduced. It is essential for policy makers to recognise and move to mitigate the growing environmental costs of beef production. Intensification to feedlots is not the answer as feedlots also have a high environmental cost. The policy imperatives proposed here represent priority national and international agendas for halting and reversing the environmental impacts of beef consumption. If left uncontrolled, the global market for beef will continue to drive regional and global change.

References

Andersen, L. E., Granger, C. W. J., Reis, E. J., Weinhold, D. and Wunder, S. (2002) *The Dynamics of Deforestation and Economic Development in the Brazilian Amazon.* Cambridge University Press, Cambridge, UK.

Andreae, M. O. and Merlet, P. (2001) Emission of trace gases and aerosols from biomass burning. *Global Biogeochemical Cycles* 15, 955-966.

Asner, G. P., Elmore, A. J., Olander, L. P., Martin, R. E. and Harris, A. T. (2004) Grazing systems, ecosystem responses, and global change. *Annual Review of Environment and Resources* 29, 261-299.

Australian Bureau of Agricultural and Resource Economics (2007) *Australian Commodities March Quarter 07.1.* Commonwealth of Australia, [Online] Available at: http://www.abareconomics.com/interactive/ac_mar07/pdf/a1.pdf.

Australian Bureau of Statistics (2006) 7123.3.55.001 - Agricultural State Profile, Queensland 2004-05. Australian Bureau of Statistics, Canberra.

Australian Greenhouse Office (2006) Queensland Greenhouse Gas Inventory 2004. Department of the Environment and Heritage, Canberra.

Barbosa, R. I. and Fearnside, P. M. (2000) Erosão do solo na Amazônia: estudo de caso na região do Apiaú, Roraima, Brasil. *Acta Amazonica* 30, 601-613.

Barbosa, R. I. and Feamside, P. M. (2005a) Above-ground biomass and the fate of carbon after burning in the savannas of Roraima, Brazilian Amazonia. *Forest Ecology and Management* 216, 295-316.

Barbosa, R. I. and Fearnside, P. M. (2005b) Fire frequency and area burned in the Roraima savannas of Brazilian Amazonia. *Forest Ecology and Management* 204, 371-384.

Barlow, J., Haugaasen, T. and Peres, C. A. (2002) Effects of ground fires on understorey bird assemblages in Amazonian forests. *Biological Conservation* 105, 157-169.

Baumert, K. A., Herzon, T. and Pershing, J. (2005) *Navigating the numbers: greenhouse gas data and international climate policy.* World Resources Institute, Washington, DC.

Betts, R. (2008) Comparing apples with oranges. *Nature Reports: Climate Change* 0801, 7-8.

Binning, C. E., Cork, S. J., Parry, R. and Shelton, D. (Eds.) (2001) *Natural Assets: An Inventory of Ecosytem Goods and Services in the Goulburn Broken Catchment*. CSIRO, Canberra.

Boadi, D. A., Wittenberg, K. M., Scott, S. L., Burton, D., Buckley, K., Small, J. A. and Ominski, K. H. (2004) Effect of low and high forage diet on enteric and manure pack greenhouse gas emissions from a feedlot. *Canadian Journal of Animal Science* 84, 445-453.

Bowen, M. E., McAlpine, C. A., House, A. P. N. and Smith, G. C. (2007) Regrowth forests on abandoned agricultural land: A review of their habitat values for recovering forest fauna. *Biological Conservation* 140, 273-296.

Brown, L. R. (2006) Feeding Seven Billion Well. *Plan B 2.0: Rescuing a Planet Under Stress and a Civilization in Trouble.* [Online] Available at: http://www.earth-policy.org/Books/PB2/PB2ch9_ss4.htm.

Butler, D. W. and Fairfax, R. J. (2003) Buffel Grass and fire in a gidgee and brigalow woodland: a case study from central Queensland. *Ecological Management and Restoration* 4, 120-125.

Cárdenas, F. (Ed.) (2000) *Desarrollo sostenible en los Andes de Colombia. Provincias del Norte, Gutiérrez y Valderrama - Boyacá, Colombia (Sustainable development in the Colombian Andes)*. IDEADE, Universidad Javeriana, Bogotá.

Chaves, M. E. and Arango, N. (Eds.) (1998) *Informe Nacional sobre el estado de la Biodiversidad en Colombia - 1997 (National Biodiversity Report - 1997)*. I. A. von Humboldt, Bogotá.

Chaves, M. E. and Santamaría, M. (Eds.) (2006) *Informe sobre el avance en el conocimiento y la información de la biodiversidad 1998-2004*. Instituto de Investigación en recursos Biológicos Alexander von Humboldt, Bogotá.

Chen, X., Hutley, L. B. and Eamus, D. (2003) Carbon balance of a tropical savanna of northern Australia. *Oecologia* 137, 405-416.

Chomitz, K. and Thomas, T. (2001) *Geographic Patterns of Land Use and Land Intensity in the Brazilian Amazon.* Development Research Group, The World Bank, Washington, D.C.

Coomes, O. T., Grimard, F., Potvin, C. and Sima, P. (2008) The fate of the tropical forest: Carbon or cattle? *Ecological Economics* 65, 207-212.

Costa, M. H., Botta, A. and Cardille, J. A. (2003) Effects of large-scale changes in land cover on the discharge of the Tocantins River, Southeastern Amazonia. *Journal of Hydrology* 283, 206-217.

Covacevich, J. A., Couper, P. J. and Mcdonald, K. R. (1998) Reptile diversity at risk in the Brigalow Belt, Queensland. *Memoirs of the Queensland Museum 42(2)* 42, 475-486.

Cox, P. M., Betts, R. A., Collins, M., Harris, P. P., Huntingford, C. and Jones, C. D. (2004) Amazonian forest dieback under climate-carbon cycle projections for the 21st century. *Theoretical and Applied Climatology* 78, 137-156.

Crowley, G. M. and Garnett, S. T. (1998) Vegetation change in the grasslands and grassy woodlands of east-central Cape York Peninsula, Australia. *Pacific Conservation Biology* 4, 132-148.

Daily, G. C. (ed) (1997). Nature's Services: Societal dependence on natural ecosystems. Island Press, Washington, D.C., 392 pp.

Dale, V. H. and Polasky, S. (2007) Measures of the effects of agricultural practices on ecosystem services. *Ecological Economics* 64. 286-296.

Dinerstein, E., Olson, D., Graham, D. J., Webster, A. L., Primm, S. A., Bookbinder, M. P. and Ledec, G. D. (1995) *A conservation assessment of the terrestrial ecoregions of Latin America and the Caribbean.* World Bank - WWF, Washington.

Dirzo, R. and Raven, P. H. (2003) Global state of biodiversity and loss. *Annual Review of Environment and Resources* 28, 137-167.

Dunn, R. R. (2004) Recovery of Faunal Communities During Tropical Forest Regeneration. *Conservation Biology* 18, 302-309.

Etter, A. and Villa, L. A. (2000) Andean forests and farming systems in part of the Eastern Cordillera (Colombia). *Mountain Research and Development* 20, 236-245.

Etter, A., McAlpine, C., Phinn, S., Pullar, D. and Possingham, H. (2006a) Characterizing a tropical deforestation front: a dynamic spatial analysis of a deforestation hotspot in the Colombian Amazon. *Global Change Biology* 12, 1409-1420.

Etter, A., McAlpine, C., Pullar, D. and Possingham, H. (2006b) Modelling the conversion of Colombian lowland ecosystems since 1940: drivers, patterns and rates. *Journal of Environmental Management* 79, 74-87.

Etter, A., McAlpine, C., Wilson, K., Phinn, S. and Possingham, H. (2006c) Regional patterns of agricultural land use and deforestation in Colombia. *Agriculture, Ecosystems and Environment* 114, 369-386.

Etter, A., McAlpine, C. and Possingham, H. (2008) A historical analysis of the spatial and temporal drivers of landscape change in Colombia since 1500. *Annals of the Association of American Geographers* 98, 1-27.

Fairfax, R. J. and Fensham, R. J. (2000) The effect of exotic pasture development on floristic diversity in central Queensland, Australia. *Biological Conservation* 94, 11-21.

FAO (1997) *State of the World's Forests 1997.* Food and Agriculture Organization of the United Nations Rome.

FAO (2002) *World Agriculture: towards 2015/2030. Summary report.* Food and Agriculture Organization of the United Nations Rome.

FAO (2006) *Food and Agriculture Statistics Global Outlook.* Food and Agriculture Organization of the United Nations [Online] Available at: http://faostat.fao.org/Portals/_Faostat/documents/pdf/world.pdf.

Fearnside, P. M. (1989) *Ocupação Humana de Rondônia: Impactos, Limites e Planejamento.* Relatórios de Pesquisa No. 5. Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brasília, DF, Brazil. 76 pp.

Fearnside, P. M. (1990) The rate and extent of deforestation in Brazilian Amazonia. *Environmental Conservation* 17, 213-226.

Fearnside, P. M. (1997a) Environmental services as a strategy for sustainable development in rural Amazonia. *Ecological Economics* 20, 53-70.

Fearnside, P. M. (1997b) Human carrying capacity estimation in Brazilian Amazonia as a basis for sustainable development. *Environmental Conservation* 24, 271-282.

Fearnside, P. M. (2000) Greenhouse gas emissions from land-use change in Brazil's Amazon region. In: Lal, R., Kimble, J. M. & Stewart, B. A. (Eds.) *Global Climate Change and Tropical Ecosystems.* Advances in Soil Science. CRC Press, Boca Raton, Florida. pp. 231-249.

Fearnside, P. M. (2001a) Land-tenure issues as factors in environmental destruction in Brazilian Amazonia: The case of Southern Para. *World Development* 29, 1361-1372.

Fearnside, P. M. (2001b) Soybean cultivation as a threat to the environment in Brazil. *Environmental Conservation* 28, 23-38.

Fearnside, P. M. (2003) Deforestation control in Mato Grosso: A new model for slowing the loss of Brazil's Amazon Forest. *Ambio* 32, 343-345.

Fearnside, P. M. (2004) A água de São Paulo e a floresta amazônica. *Ciência Hoje* 34, 63-65.

Fearnside, P. M. (2005) Deforestation in Brazilian Amazonia: history, rates, and consequences. *Conservation Biology* 19, 680-688.

Fearnside, P. M. (2008) Amazon forest maintenance as a source of environmental services. *Anais da Academia Brasileira de Ciencias* 80, 101-114.

Fearnside, P. M. and Barbosa, R. I. (1998) Soil carbon changes from conversion of forest to pasture in Brazilian Amazonia. *Forest Ecology and Management* 108, 147-166.

Fearnside, P. M. and Laurance, W. F. (2004) Tropical deforestation and greenhouse-gas emissions. *Ecological Applications* 14, 982-986.

Foley, J. A., Asner, G. P., Costa, M. H., Coe, M. T., DeFries, R., Gibbs, H. K., Howard, E. A., Olson, S., Patz, J., Ramankutty, N. and Snyder, P. (2007) Amazonia revealed: forest degradation and loss of ecosystem goods and services in the Amazon Basin. *Frontiers in Ecology and Environment* 5, 25-32.

Foley, J. A., Coe, M. T., Scheffer, M. and Wang, G. L. (2003) Regime shifts in the Sahara and Sahel: Interactions between ecological and climatic systems in northern Africa. *Ecosystems* 6, 524-539.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharik, C. J., Monfreda, C., Patz, J. A., Prentice, I. C., Ramankutty, N. and Snyder, P. K. (2005) Global consequences of land use. *Science* 309, 570-574.

Gerbens-Leenes, P. W. and Nonhebel, S. (2002) Consumption patterns and their effects on land required for food. *Ecological Economics* 42, 185-199.

Gifford, R. M. and Howden, M. (2001) Vegetation thickening in an ecological perspective: significance to national greenhouse gas inventories. *Environmental Science & Policy* 4, 59-72.

Hannah, D., Woinarski, J. C. Z., Catterall, C. P., Mccosker, J. C., Thurgate, N. Y. and Fensham, R. J. (2007) Impacts of clearing, fragmentation and disturbance on the bird fauna of eucalypt savanna woodlands in central Queensland, Australia. *Austral Ecology* 32, 261-276.

Hecht, S. (1993) The logic of livestock and deforestation in Amazonia. Considering land markets, value of ancilliaries, the larger macroeconomic context and individual economic strategies. *Bioscience* 43, 687-695.

Henry, B. K., Danaher, T., Mckeon, G. M. and Burrows, W. H. (2002) A review of the potential role of greenhouse gas abatement in native vegetation management in Queensland's rangelands. *Rangeland Journal* 24, 112-132.

Hobbs, R. J. and Hopkins, A. J. M. (1990) From frontier to fragments: European impact on Australia's vegetation. *Proceedings of the Ecological Society of Australia* 16, 93-114.

Hoffmann, W. A. and Haridasan, M. (2008) The invasive grass, Melinis minutiflora, inhibits tree regeneration in a Neotropical savanna. *Austral Ecology* 33, 29-36.

Howden, S. M., Moore, J. L., Mckeon, G. M. and Carter, J. O. (2001) Global change and the mulga woodlands of southwest Queensland: greenhouse gas emissions, impacts, and adaptation. *Environment International* 27, 161-166.

Howden, S. M., White, D., Mckeon, G. M., Scanlan, J. C. and Carter, J. O. (1994) Methods for exploring management options to reduce greenhouse gas emissions from tropical grazing systems. *Climatic Change* 27, 49:70.

IDEAM (2008) *Memoirs "Workshop for the National Greenhouse Gases Inventory: 2000-2004" Preparation for IPCC.* Instituto de Estudios Ambientales IDEAM, Ministerio del Ambiente, Vivienda y Desarrollo Territorial (MAVDT), Bogotá DC.

INPE (2008) *Projeto Prodes.* Instituto Nacional de Pesquisas Espaciais, Brazil, [Online] http://www.inpe.br/.

IPCC (2007a) *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Inter-governmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2007b) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 996 pp.

Kaimowitz, D., Mertens, B., Wunder, S. and Pacheco, P. (2004) *Hamburger Connection Fuels Amazon Destruction.* CIFOR, Bogor, Indonesia.

Keyzer, M. A., Merbis, M. D., Pavel, I. F. P. W. and Van Wesenbeeck, C. F. A. (2005) Diet shifts towards meat and the effects on cereal use: can we feed the animals in 2030? *Ecological Economics* 55, 187-202.

Lamb, D., Erskine, P. D. and Parrotta, J. A. (2005) Restoration of degraded tropical forest landscapes. *Science* 310, 1628-1632.

Lambin, E. F., Geist, H. J. and Et Al. (2006) Introduction: local processes with global impacts. In: Lambin, E. F. & Geist, H. J. (Eds.) *Land-Use and Land-Cover Change: Local Processes and Global Impacts.* Springer-Verlag, Berlin. pp. 1-8.

Laurance, W. F. (2006) Fragments and fire: alarming synergisms among forest disturbance, local climate change, and burning in the Amazon. In: Laurance, W. F. & Peres, C. A. (Eds.) *Emerging Threats to Tropical Forests.* University of Chicago Press, Chicago, USA. pp. 87-103.

Laurance, W. F., Ferreira, L. V., Rankin De Merona, J. M. and Laurance, S. G. (1998) Rain forest fragmentation and the dynamics of Amazonian tree communities. *Ecology* 79, 2032-2040.

Laurance, W. F., Cochrane, M. A., Bergen, S., Fearnside, P. M., Delamonica, P., Barber, C., D'angelo, S. and Fernandes, T. (2001a) The future of the Brazilian Amazon. *Science* 291, 438-439.

Laurance, W. F., Fearnside, P. M., Cochrane, M. A., D'angelo, S., Bergen, S. and Delamonica, P. (2001b) Development of the Brazilian Amazon - Response. *Science* 292, 1652-1654.

Laurance, W. F., Lovejoy, T. E., Vasconcelos, H. L., Bruna, E. M., Didham, R. K., Stouffer, P. C., Gascon, C., Bierregaard, R. O., Laurance, S. G. and Sampaio, E. (2002) Ecosystem decay of Amazonian forest fragments: A 22-year investigation. *Conservation Biology* 16, 605-618.

Laurance, W. F., Albernaz, A. K. M., Fearnside, P. M., Vasconcelos, H. L. and Ferreira, L. V. (2004) Deforestation in Amazonia. *Science* 304, 1109-1109.

Laurance, W. F., Albernaz, A. K. M., Fearnside, P. M., Vasconcelos, H. L. and Ferreira, L. V. (2005) Underlying causes of deforestation - Response. *Science* 307, 1046-1047.

Laurance, W. F., Nascimento, H. E. M., Laurance, S. G., Andrade, A. C., Fearnside, P. M., Ribeiro, J. E. L. and Capretz, R. L. (2006) Rain forest fragmentation and the proliferation of successional trees. *Ecology* 87, 469-482.

Lepers, E., Lambin, E. F., Janetos, A. C., Defries, R., Achard, F., Ramankutty, N. and Scholes, R. J. (2005) A synthesis of information on rapid land-cover change for the period 1981-2000. *Bioscience* 55, 115-124.

Ludwig, J. A., Eager, R. W., Liedloff, A. C., Mccosker, J. C., Hannah, D., Thurgate, N. Y., Woinarski, J. C. Z. and Catterall, C. P. (2000) Clearing and grazing impacts on vegetation patch structure and fauna counts in eucalypt woodland, Central Queensland. *Pacific Conservation Biology* 6, 254-272.

Marengo, J. A. (2006) On the hydrological cycle of the Amazon Basin: a historical review and current state-of-the-art. *Revista Brasileira de Meteorologia* 21, 1-19.

MAVDT (2007) ZONAS DE RESERVA FORESTAL EN COLOMBIA. Ministerio del Ambiente, Vivienda y Desarrollo Territorial, Bogotá DC, (http://www.upme.gov.co/guia_ambiental/carbon/areas/reservas/indice.htm#1.%20ZONAS%20DE%20RESERVAS%20FORESTALES%20EN%20COLOMBIA).

McAlpine, C. A., Fensham, R. J. and Temple-Smith, D. E. (2002) Biodiversity conservation and vegetation clearing in Queensland: principles and thresholds. *The Rangeland Journal* 24, 36-55.

McAlpine, C. A., Syktus, J., Deo, R. C., Lawrence, P. J., Mcgowan, H. A., Watterson, I. G. and Phinn, S. R. (2007) Modeling the impact of historical land cover change on Australia's regional climate. *Geophysical Research Letters* 34, 6.

Melo, J. O. (1998) *Historia de Colombia: la dominación española (Colombian history: the Spanish domination).* Biblioteca Familiar de la Presidencia de la República, Bogotá.

Mertens, B., Poccard-Chapuis, R., Piketty, M. G., Lacques, A. E. and Venturieri, A. (2002) Crossing spatial analyses and livestock economics to understand deforestation processes in the Brazilian Amazon: the case of Sao Felix do Xingu in South Para. *Agricultural Economics* 27, 269-294.

Millennium Ecosystem Assessment (2003) *Ecosystems and Human Well-Being: A Framework for Assessment.* Island Press, Washington, D.C.

Mistry, J. and Berardi, A. (2005) Assessing Fire Potential in a Brazilian Savanna Nature Reserve1. *Biotropica* 37, 439-451.

Moran, E. F. (1993) Deforestation and land-use in the Brazilian Amazon. *Human Ecology* 21, 1-21.

Myers, N. and Kent, J. (2004) *The New Consumers: The Influence of Affluence on the Environment.* Island Press, Washington, D.C..

Nascimento, H. E. M. and Laurance, W. F. (2004) Biomass dynamics in Amazonian forest fragments. *Ecological Applications* 14, S127-S138.

Ocampo, J. A. (Ed.) (1987) *Historia económica de Colombia (Economic history of Colombia).* Siglo XXI Editores - Fedesarrollo, Bogotá.

Pagiola, S., Agostini, P., Gobbi, J., De Haan, C., Ibrahim, M., Murgueitio, E., Ramirez, E., Rosales, M. and Ruiz, J. P. (2004a) *Paying for Biodiversity Conservation Services in Agricultural Landscapes. Environment Departmnt Paper No. 96.* The World Bank Environment Department, Washington, D.C.

Pagiola, S., Von Ritter, K. and Bishop, J. (2004b) *Assessing the Economic Value of Ecosystem Conservation.* Environment Department Paper No. 101. The World Bank Environment Department, Washington, D.C.

Peres, C. and Michalski, F. (2006) Synergistic effects of habitat disturbance and hunting in Amazonian forest fragments. In: Laurance, W. & Peres, C. (Eds.) *Emerging Threats to TropicalForests.* University of Chicago Press, Chicago, USA. pp. 105-127.

Pielke, R. A. (2005) Land use and climate change. *Science* 310, 1625-1626.

Pielke, R. A., Adegoke, J. O., Chase, T. N., Marshall, C. H., Matsui, T. and Niyogi, D. (2007) A new paradigm for assessing the role of agriculture in the climate system and in climate change. *Agricultural and Forest Meteorology* 142, 234-254.

Queensland Government (2004) *Vegetation Management and Other Legislation Amendment Act 2004*. [Online] Available at: http://www.legislation.qld.gov.au/LEGISLTN/ACTS/2004/04AC001.pdf.

Ramankutty, N. and Foley, J. A. (1999a) Estimating historical changes in global land cover: Croplands from 1700 to 1992. *Global Biogeochemical Cycles* 13, 997-1027.

Ramankutty, N. and Foley, J. A. (1999b) Estimating historical changes in land cover: croplands from 1700 to 1992. *Global Biogeochemical Cycles* 13, 997-1027.

Ramankutty, N. and Foley, J. A. (1999c) Estimating historical changes in land cover: North American croplands from 1850 to 1992. *Global Ecology and Biogeography* 8, 381-396.

Rifkin, J. (1992) *Beyond Beef: The Rise and Fall of the Cattle Culture.* Dutton, New York.

Rijsberman, F. J. (2006) Water scarcity: fact or fiction? *Agricultural Water Management* 80, 5-22.

Rolfe, J. (2002) Economics of vegetation clearance in Queensland. *The Rangeland Journal* 24, 152-169.

Rosas, G. and Perry, S. (2002) *Algunos aspectos de la competitividad del ganado y la carne en Colombia.* Frigorífico Guadalupe, Bogotá.

Sampaio, G., Nobre, C., Costa, M. H., Satyamurty, P., Soares, B. S. and Cardoso, M. (2007) Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion. *Geophysical Research Letters* 34, L17709, doi:10.029/2007GL030612.

Santilli, M., Moutinho, P., Schwartzman, S., Nepstad, D., Curran, L. and Nobre, C. (2005) Tropical deforestation and Kyoto Protocol. *Climatic Change* 71, 267-276.

Seabrook, L., McAlpine, C. and Fensham, R. J. (2006) Cattle, crops and clearing: regional drivers of landscape change in the Brigalow Belt, Queensland, Australia 1840-2004. *Landscape and Urban Planning* 78, 373-385.

Sharp, B. R. and Whittaker, R. J. (2003) The irreversible cattle-driven transformation of a seasonally flooded Australian savanna. *Journal of Biogeography* 30, 783-802.

Silveira, J. P. (2001) Development of the Brazilian Amazon. *Science* 292, 1651-1652.

Smeraldi, R. and May, P. (2008) *The Cattle Realm: A New Phase in the Livestock Colonization of Brazilian Amazonia.* Amigos da Terra (Friends of the Earth) Amazônia Brasileira, São Paulo, Brazil.

Smil, V. (2002) Worldwide transformation of diets, burdens of meat production and opportunities for novel food proteins. *Enzyme and Microbial Technology* 30, 305-311.

Soares-Filho, B., Alencar, A., Nepstad, D., Cerqueira, G., Vera Diaz, M. D. C., Rivero, S., Solorzano, L. and Voll, E. (2004) Simulating the response of land-cover changes to road paving and governance along a major Amazon highway: the Santarem-Cuiaba corridor. *Global Change Biology* 10, 745-764.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. and De Haan, C. (2006) *Livestock's Long Shadow: Environmental Issues and Options.* Food and Agriculture Organization of the United Nations, Rome.

Steinfeld, H. and Wassenaar, T. (2007) The role of livestock production in carbon and nitrogen cycles. *Annual Review of Environment and Resources* 32, 271-294.

Stern, N. (2006) Stern Review: The Economics of Climate Change. Cambridge University Press, Cambridge, UK.

Subak, S. (1999) Global environmental costs of beef production. *Ecological Economics* 30, 79-71.

Tilman, D., Fargione, J., Wolff, B., D'antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W. H., Simberloff, D. and Swackhamer, D. (2001) Forecasting agriculturally driven global environmental change. *Science* 292, 281-284.

United Nations Secretariat (2007) *World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2005 Revision.* Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. Available online at http://esa.un.org/unpp (accessed September 2007).

USDA (1985) *Beef Promotion and Research Act of 1985.* United States Department of Agriculture, [Online] Available: http://www.ams.usda.gov/lsg/mpb/beef/beefact.pdf.

Veiga, J. B., Alves, A. M., Poccard-Chapuis, R., Thales, M. C., Da Costa, P. A., Grijalva, J. O., Chamba, T. V., Costa, R. M., Piketty, M.-G. and Tourrand, J.-F. (2001) *Cattle ranching, pasture management and deforestation in Brazil, Peru and Ecuador. The case of Para.* Resarch Report of IAI Project. University of Florida, CLAS, Gainesville. Florida, U.S.A.

Vitousek, P. M., Mooney, H. A., Lubchenco, J. and Melillo, J. M. (1997) Human domination of Earth's ecosystems. *Science* 277, 494-499.

Williams, D. G. and Baruch, Z. (2000) African grass invasion in the Americas: ecosystem consequences and the role of ecophysiology. *Biological Invasions* 2, 123-140.

Woinarski, J. C. Z. and Ash, A. J. (2002) Responses of vertebrates to pastoralism, military land use and landscape position in an Australian tropical savanna. *Austral Ecology* 27, 311-323.

Woinarski, J. C. Z., Mackey, B., Nix, H. A. and Traill, B. (2007) *The Nature of Northern Australia: Natural Values, Ecological Processes and Future Prospects.* Australian National University E Press, Canberra.

Yepes, F. (2001) Ganaderia y transformacion de ecosistemas: un analisis ambiental de la politica de apropiacion territorial. In: Palacio, G. (Ed.) *Naturaleza en disputa: Ensayos de historia ambiental de Colombia 1850-1995.* Universidad Nacional de Colombia, Bogotá. pp. 117-172.

FIGURE CAPTIONS

Fig. 1. Conceptual model of the socio-economic drivers of increased global demand for beef and resulting impacts and feedbacks on the regional and global environment.

Fig. 2a. Beef cattle numbers in Queensland and Australia, 1861-2005. (data from Australian Bureau of Statistics).

Fig. 2b. Annual clearing rates for pasture and in total for Queensland, 1988-2005 (left axis) and average price of beef (right axis). (Pasture and clearing data from Queensland Department of Natural Resources and Water. Cattle price data from Australian Bureau of Statistics).

Fig. 3. Land cover in Queensland. Note it is not possible to separate native from exotic pasture. The pastures which dominate the western half of the state are predominantly native pasture while the pastures in the east and the deforested areas are dominated by exotic pasture. (data from Queensland Department of Natural Resources and Water).

Fig. 4. Estimated size of the cattle herd of Colombia by region the historical periods (data derived from Etter et al., 2008).

Fig. 5. Land use in Colombia showing cattle grazing in introduced and natural pastures. Introduced pastures largely coincide with deforested areas. (data derived from Etter et al., 2006c).

Fig. 6. Rapid expansion of the cattle herd in Brazilian Amazonia compared with the rest of Brazil (data from the Brazilian Institute for Geography and Statistics).

Fig.7. Deforestation in the Brazilian Amazon, circa 2001 (courtesy of Worldwatch Institute).

Figure 1

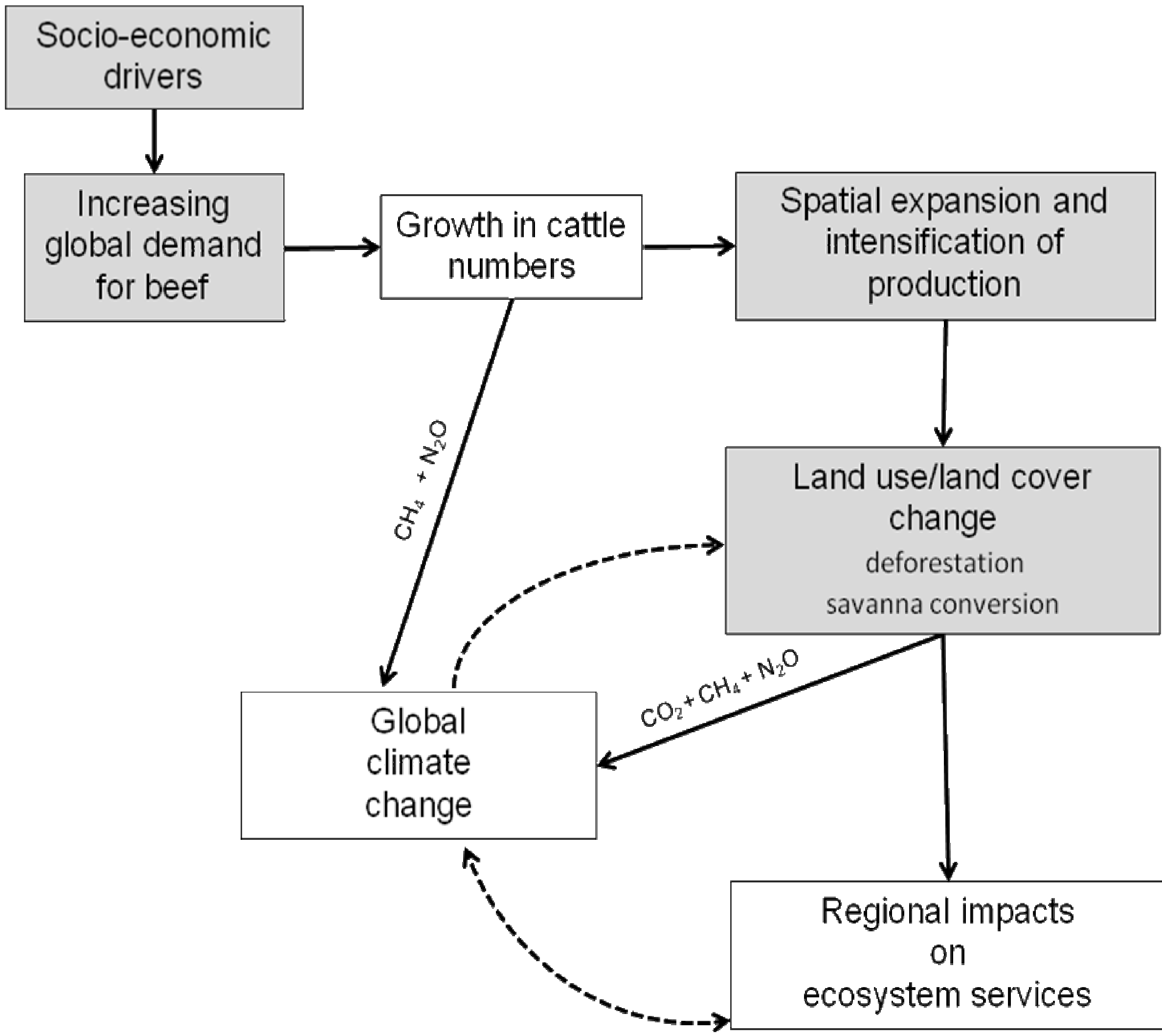

Socio-economic drivers
Increasing global demand for beef
Growth in cattle numbers
Spatial expansion and intensification of production
CH_4 + N_2O
Land use/land cover change
deforestation
savanna conversion
CO_2 + CH_4 + N_2O
Global climate change
Regional impacts on ecosystem services

Figure 2a

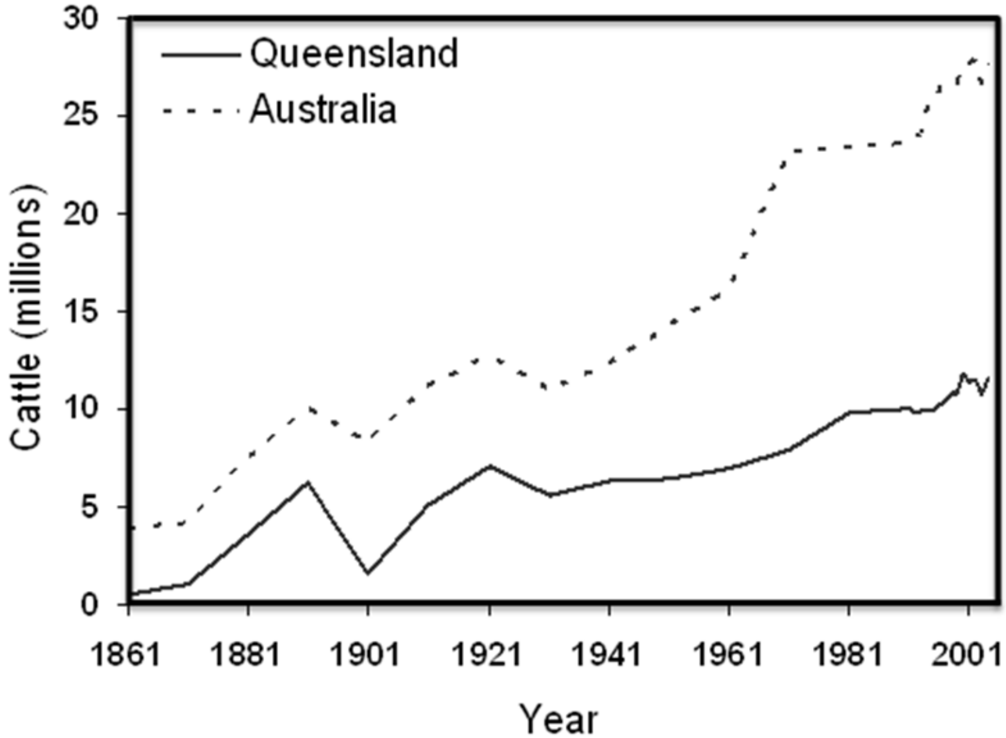

Queensland
Australia
Cattle (millions)
30
25
20
15
10
5
0
1861
1881
1901
1921
1941
1961
1981
2001
Year

Figure 2b

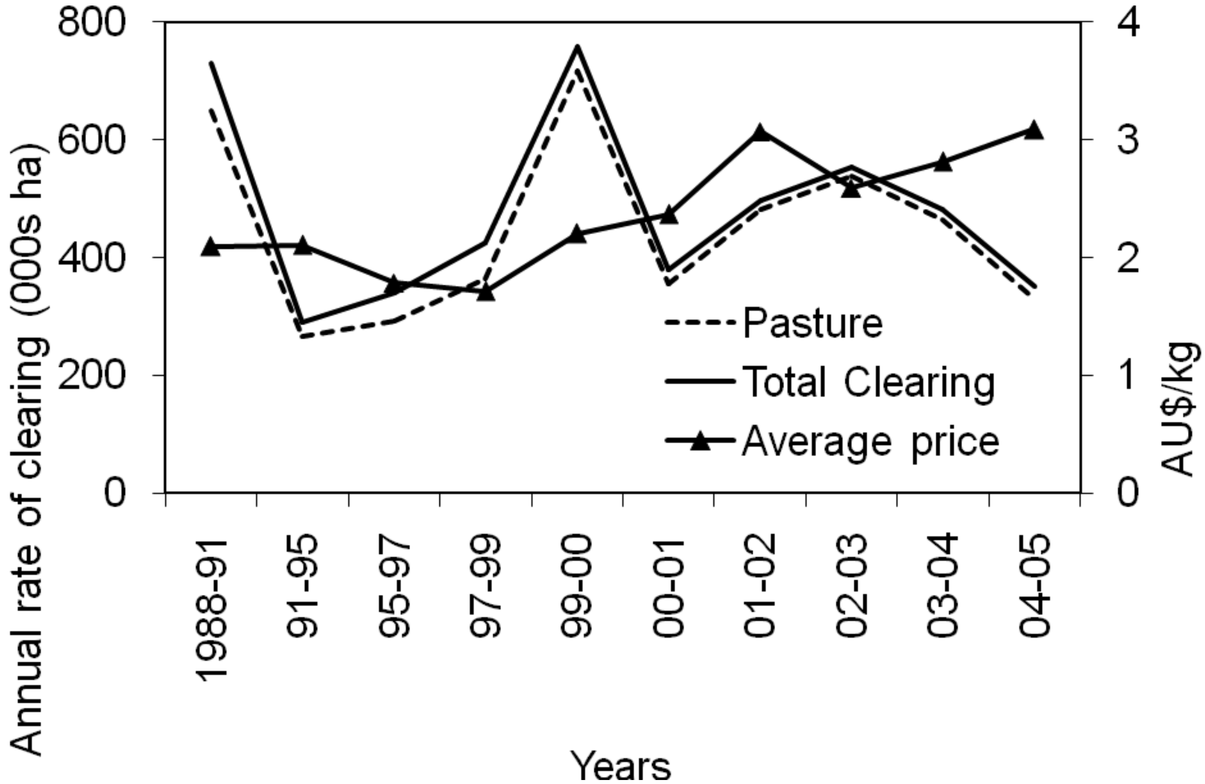

800
600
400
200
0
4
3
2
1
0
Annual rate of clearing (000s ha)
AU$/kg
Pasture
Total Clearing
Average price
1988-91
91-95
95-97
97-99
99-00
00-01
01-02
02-03
03-04
04-05
Years

Figure 3

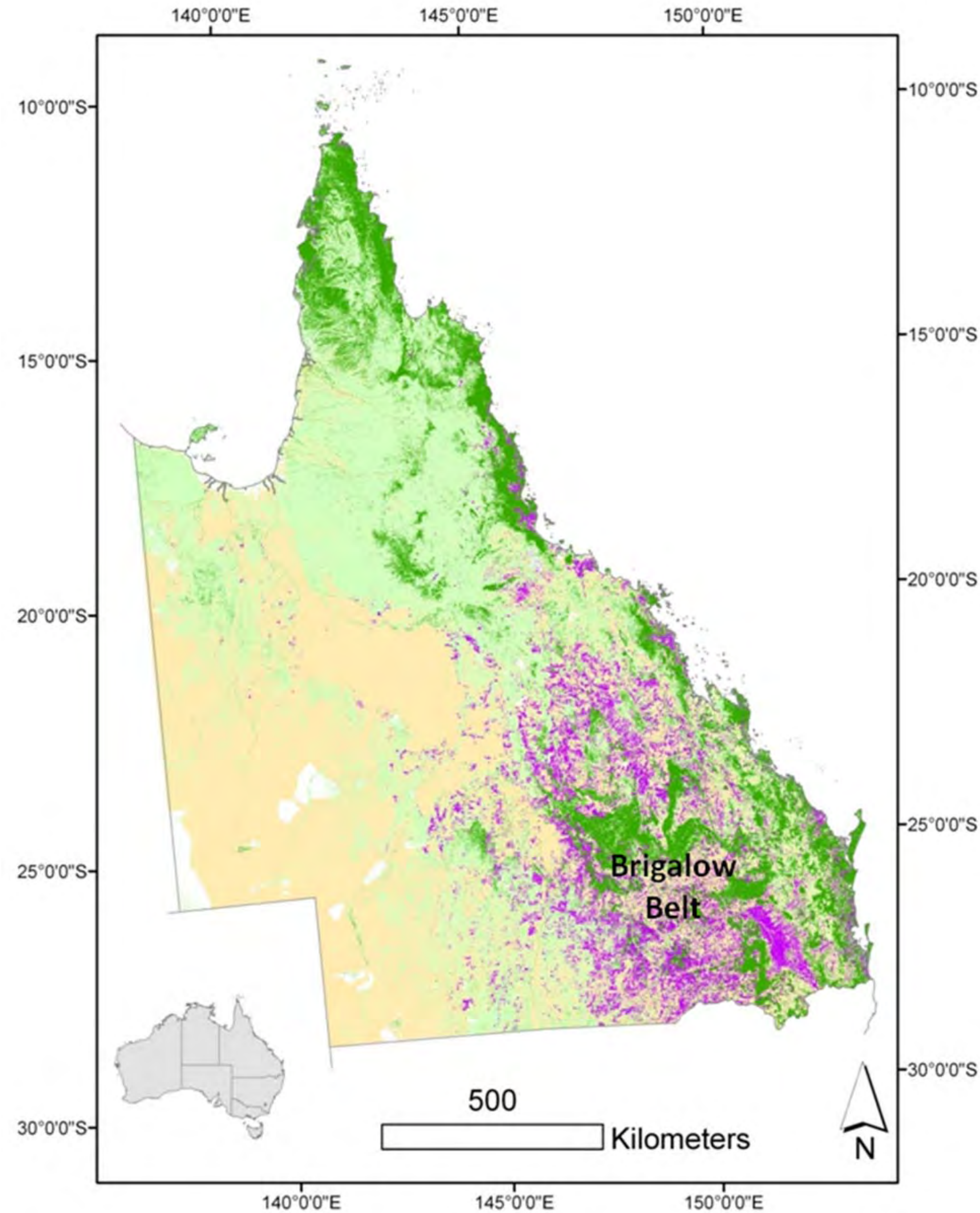

140°0'0"E
145°0'0"E
150°0'0"E
10°0'0"S
15°0'0"S
20°0'0"S
25°0'0"S
30°0'0"S
Brigalow
Belt
500
Kilometers
N

Figure 4

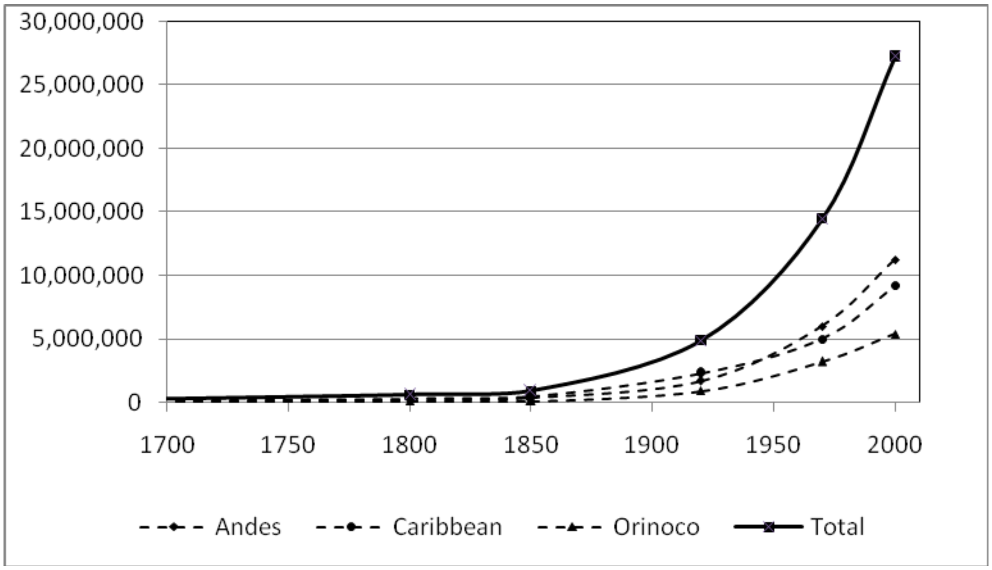

30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
1700
1750
1800
1850
1900
1950
2000
Andes
Caribbean
Orinoco
Total

Figure 5

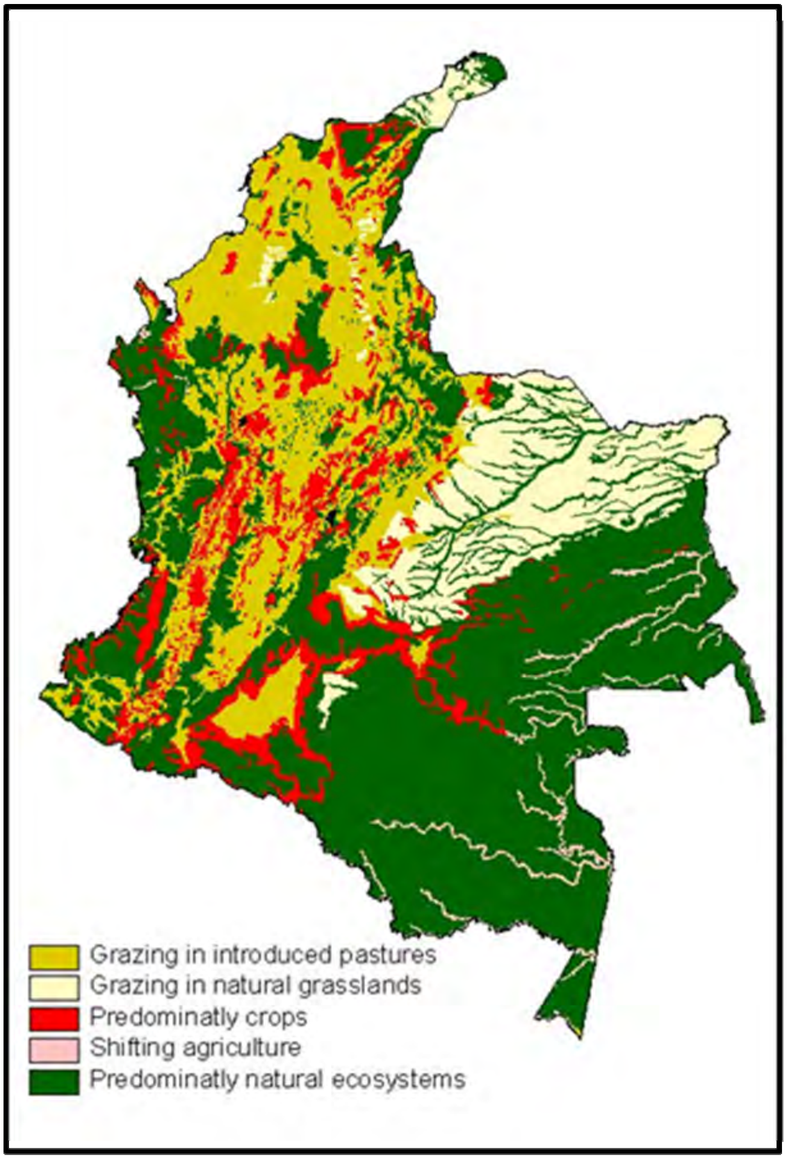

Grazing in introduced pastures
Grazing in natural grasslands
Predominatly crops
Shifting agriculture
Predominatly natural ecosystems

Figure 6

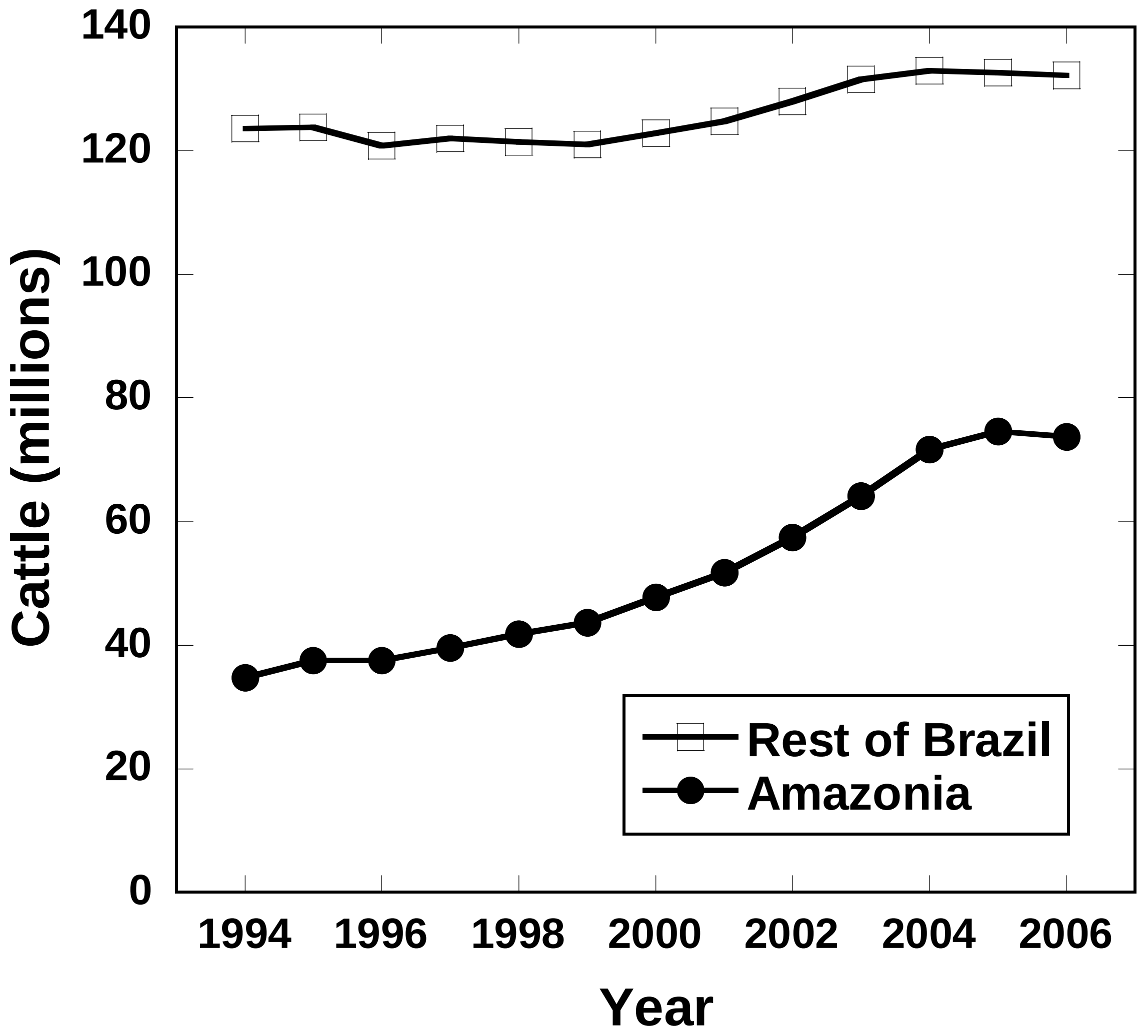
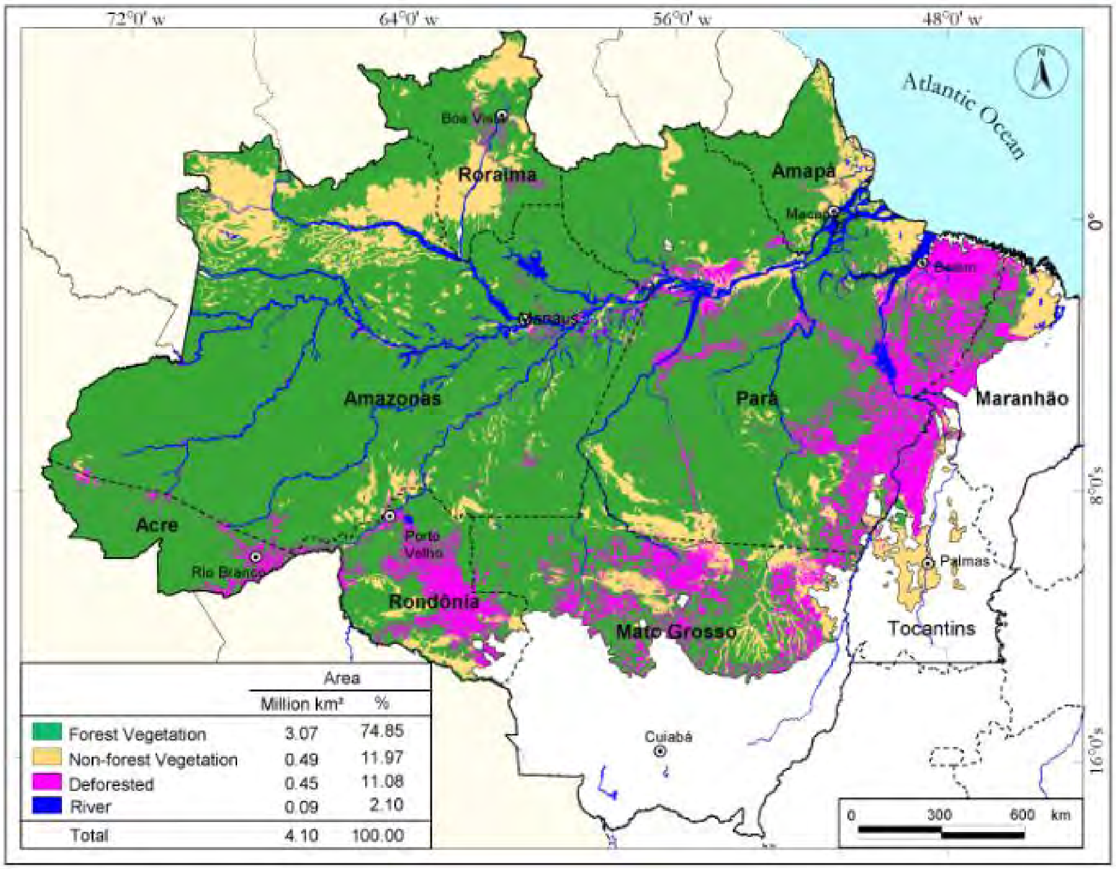

140
120
100
80
60
40
20
0
Cattle (millions)
1994
1996
1998
2000
2002
2004
2006
Year
Rest of Brazil
Amazonia

Figure 7


72°0' w
64°0' w
56°0' w
48°0' w
Atlantic Ocean
0°
8°0's
16°0's
Boa Vista
Roraima
Amapá
Macapá
Belém
Manaus
Amazonas
Pará
Maranhão
Acre
Rio Branco
Porto Velho
Rondônia
Mato Grosso
Palmas
Tocantins
Cuiabá
Area
Million km²
%
Forest Vegetation 3.07 74.85
Non-forest Vegetation 0.49 11.97
Deforested 0.45 11.08
River 0.09 2.10
Total 4.10 100.00
0 300 600 km