

Assessing linkages between agriculture and biodiversity in Central America: Historical overview and future perspectives

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Executive summary

Agriculture is widely considered the single most important threat to biodiversity conservation and the greatest driver of habitat destruction and change in Central America. Historically, agriculture has had a negative impact on biodiversity conservation primarily through the expansion of the agricultural frontier, at the expense of natural habitat. Today, the nature of the threat of agriculture to biodiversity conservation has changed. While agriculture continues to drive deforestation in the few remaining, remote areas where the agricultural frontier still exists, the main impact of agriculture is now due to the intensification of existing agricultural systems (and the concurrent increased use of pesticides, fertilizers and other inputs, the loss of hedgerows/live fences and natural habitats within these systems and the greater pressure on the remaining natural resources) and to a lesser degree, changes in the configuration of agricultural landscapes.

A wide array of social, economic and institutional factors have contributed to (and continue to drive) the expansion of the agricultural frontier, the intensification of existing agricultural systems and changes in agricultural landscapes within the region. These include demographic and social factors, poverty levels, land tenure, government policies and laws, international prices and consumption tendencies, expansion of available infrastructure, market failures, technological factors, subsidies and tariff protection, and gaps in information and extension services, among other factors. In particular, the growing population and increased demand for land and agricultural products make it likely that the pressure to increase agricultural production (either through the conversion of additional habitat to agricultural production and/or the intensification of production of already existing agricultural areas) will intensify in upcoming decades. The eventual implementation of CAFTA is also likely to strongly affect agricultural activities in the region through the establishment of new laws that force exporters to comply with local environmental regulations and the creation of new markets for some agricultural products.

Agriculture can affect biodiversity in a number of ways. The most immediate way in which agriculture impacts biodiversity is through the conversion, destruction or modification of natural habitats, the fragmentation of remaining natural habitat and the concurrent loss of landscape connectivity. However, other direct impacts include the degradation of the remaining habitat through hunting, plant or animal extraction and entry by domestic animals, the introduction and potential of non-native species (including GMO's and potentially invasive species), and the pollution of streams, rivers and near-shore marine ecosystems with fertilizers, pesticides and herbicides. In addition to these direct effects, agriculture may also impact biodiversity indirectly through changes in ecological processes (e.g., water cycles, fires, pest dynamics), the invasion of exotic species and changes in infrastructure that usually accompany agriculture and may further reduce natural habitat availability.

Different agricultural production systems vary in the extent to which they affect biodiversity, due to differences in their requirement for new cleared land, pesticide and fertilizer use, susceptibility to soil erosion, cropping intensity, area occupied, and spatial configuration in the landscape, among other factors. Although the impact of individual production systems is likely to be site-specific and depend on the particular social, economic, ecological and biophysical conditions, a few production systems have

disproportionately affected biodiversity in the region. These include cattle, coffee, banana and sugarcane production (all produced for export), which have consumed large areas of land and fueled the expansion of the agricultural frontier into new areas.

There are many ways in which the negative effects of agriculture on biodiversity can be mitigated or even abated. Efforts to mitigate the impact of agriculture on biodiversity should focus not only on ensuring that agriculture does not extend into existing protected areas or remaining remnants of natural habitats, but also on finding ways to intensify production systems without the associated negative impacts on biodiversity and encourage landscape-level changes which positively affect conservation efforts. A variety of technological practices are available to enhance the conservation value of individual production systems or design and manage agricultural landscapes for conservation goals. There are also many opportunities for mitigating the impact of agriculture on biodiversity through changes in the legal framework, enhanced institutional support and the implementation of market based approaches, however these issues are complex and not easily or quickly resolved without considerable political will and government intervention. The key issue is how to create the appropriate incentives, policies, laws and socioeconomic conditions under which these sustainable practices can be applied and sustained, in such a way that the needs of the growing population are also met.

General introduction

Central America is considered one of the world's biological hotspots, and is a priority area for conservation efforts. Covering an estimated 0.5% of the world's terrestrial surface, it is home to roughly 7% of the world's plant and animal species, including many endemic species (CCAD, 2003). Although almost all of Central America was originally covered by forest, the region has been heavily impacted by agriculture (particularly coffee, banana, sugarcane and cattle production) and most of the forests have been converted to pasture and cropland, or residential or urban areas. It is estimated that currently only 20% of the region contains dense forest cover and that much of this remaining cover is already highly fragmented or under threat of conversion (CCAD, 1998). Historically, much of the deforestation and conversion to forest occurred in the fertile valleys of the mountainous central region and in the dry Pacific lowlands (where the majority of Central America's populations live); however in the last half century the agricultural frontier has expanded to the east affecting the forests of the Caribbean lowlands and reducing previously extensive forests (Utting, 1993; Pasos *et al.*, 1994).

Agriculture is widely considered the single most important threat to biodiversity conservation and the greatest driver of habitat destruction and change in the region (Heywood and Watson, 1995; McNeely and Scherr, 2003). Since agriculture is practiced on lands that were previously covered by forests or other natural habitats and involves the introduction of species of interest primarily to humans, it necessarily results in the modification, conversion or fragmentation of natural habitats and their communities (Tilman, 2001; McNeely and Scherr, 2003; Donald, 2004). This impact can occur at all levels of biodiversity- from genes to species to ecosystems- and can affect both wild and domesticated diversity (Heywood and Watson, 1995). With the Central American population growing at an estimated rate of 2.6% annually (Proyecto Estado de la Region, 1999) it is likely that the pressure to increase agriculture production (either through the conversion of additional habitat to agricultural production and/or the intensification of production of already existing agricultural areas) will intensify in upcoming years. At the same time, the threat to the remaining natural habitats and their biodiversity (including those occurring in protected areas) will

become more acute. Consequently, it is important to understand how agriculture affects biodiversity and seek ways in which to prevent or mitigate these adverse effects while ensuring sustainable agricultural production that can fulfill the growing food demand and maintain local livelihoods (Srivastava, 1996; Srivastava *et al.*, 1996; 1998; Thrupp, 1998; McNeely and Scherr, 2003).

The objective of this report is to explore the impact of agriculture on biodiversity conservation in Central America, identify the factors which perpetuate or exacerbate agricultural systems or management practices that adversely impact biodiversity conservation, and examine different strategies and approaches that could be used to potentially mitigate some of the negative impacts of agriculture on biodiversity conservation, either by making the agricultural systems more compatible with biodiversity conservation, or by removing the stimuli for agricultural expansion into remaining natural areas or unsustainable agricultural practices. We begin by introducing the Central American region, its biodiversity and main agricultural systems. We then discuss the three main tendencies of agriculture in the region -the expansion of the agricultural frontier, the intensification of existing agricultural systems, and changes in the composition and structure of agricultural landscapes - and the factors that cause these changes. Next, we examine how agriculture affects biodiversity in the region and the factors that influence these effects. Finally, we consider ways in which the impact of agriculture on biodiversity conservation can be mitigated through both the technological, macroeconomic, regulatory and market-based interventions.

Throughout the paper, we use ‘agriculture’ to refer to “the process of modifying natural ecosystems to provide more goods and services for people through the nurturing of domesticated species of plants and animals” (McNeely and Scherr, 2003). In its broadest sense, agriculture is taken to include ‘all forms of husbandry, including crop and livestock production, aquaculture and tree plantations’ (McNeely and Scherr, 2003); however in this paper we limit our discussion to domesticated crops and livestock. By ‘biodiversity’ we refer to the definition in the United Nations Convention on Biological Diversity which states that it is ‘the variability among living organisms from all sources including, inter alia, terrestrial, marine and the aquatic ecosystems and the ecological

complexes of which they are part; this includes diversity within species, between species and of ecosystems” (Glowka *et al.*, 1994).

Methods and scope of work

This report summarizes the main linkages between agriculture and biodiversity in Central America, focusing on the impacts on ‘wild’ biodiversity. We do not present information on ‘planned’ biodiversity (or agrobiodiversity), as this topic is extensive and would merit another full report (e.g. Thrupp, 1998). The information in this report stems from a detailed review of available literature (both scientific and grey literature) on the linkages between agriculture and biodiversity, as well as information available on websites of organizations that work in agriculture, biodiversity conservation and/or sustainable development. In all, >550 references were consulted, and >65 web sites visited (see Appendix 1 for complete summary of bibliography consulted). Additional information was obtained through conversations and correspondence with >50 experts (Appendix 2). Detailed information on the agricultural systems and agricultural threats present in individual ecoregions was also obtained from questionnaires sent to 50 questionnaire experts, of whom 10 answered. Despite considerable effort to obtain and summarize the current knowledge of relationships between agriculture and biodiversity in Central America, some relevant details may be missing due to the lack of documentation of relevant experiences, the difficulty of accessing ‘grey’ literature and the incompleteness of available information.

Introduction to Central America

Central America is composed of seven countries (Belize, Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica and Panama) that cover an area of 541,190 km², and extend a total of 1,440 km from north to south (with a width of 480 km at its widest point; Vaughan and Mo, 1994). The region is considered a developing region with a mean gross domestic product per capita of 1,843 US dollars (although this varies greatly across countries) and an economy that is highly dependent on agriculture as a source of income and employment. The region currently has a total of 38.7 million inhabitants, which are a mixture of peoples of indigenous, European and African descent, and is

rapidly growing. By 2015 it is expected to have a population of 49.8 million inhabitants (Proyecto Estado de la Region, 2003). The region is culturally, socio-economically and geographically diverse, but shares certain characteristics such as the strong Spanish colonial influence (with the exception of Belize which was colonized by the British), a rich biodiversity, a rapidly growing population and a strong dependence on agriculture and the natural resource base (Vaughan and Mo, 1994).

The region can be divided into three major ecological zones- the lowland area of the Caribbean slope and northern Guatemala, the range of mountains and valleys that run through the central part of the isthmus, and the Pacific lowlands (Utting, 1993; Pasos, 1994). The lowland region on the Caribbean side is characterized by high rainfall (2000 to 6000 mm a year) and a humid tropical climate, and is the area where most of the remaining dense forest cover remains. The mountainous zone which runs through the central part of the isthmus has a more temperate climate (with cooler temperatures and lower rainfall) and contains broadleaf forests in the south and pine forests in the northern part of the isthmus (Guatemala and Honduras), and many areas are affected by the trade winds. Much of this region has been converted to agriculture (particularly coffee and livestock production) and contains high population densities. In contrast, the Pacific lowlands are characterized by a tropical dry climate (with a distinct dry season of 4 to 6 months and average annual rainfall of 1,000 mm to 1,500 mm) and deciduous broadleaf forest. Much of the Pacific lowland forest has been converted to crop and pasture land and only small remnants of dry forest remain. The three major ecological zones can be further divided into 7 major habitat types (Tropical moist broadleaf forest, Tropical dry broadleaf forest, Tropical and subtropical coniferous forests, Montane grasslands, Deserts and xeric scrublands, Atlantic Mangroves, and Pacific mangroves), which in turn are further subdivided into 24 ecoregions (Dinerstein *et al.*, 1995, Appendix 3).

Biodiversity in Central America

As a land bridge between North and South America, Central America contains a unique mixture of flora and fauna where species from the Nearctic and the Neotropics overlap. The varied topography, geology, vegetation and drainage patterns within the region result in a rich array of vegetation types and animal communities. More than 24,000

plant species, 521 mammal species, 1,193 bird species, 685 reptile species and 460 amphibian species have been identified within Mesoamerica (a region that includes Central America and southern Mexico) many of which are endemic to the region (CCAD, 2003, Table 1).

Table 1. Diversity and endemism for Mesoamerica (Central America and southern Mexico) by taxonomic group.

Taxonomic group	Species	Endemic species	Percent endemism
Plants	24,000	5,000	21.0
Mammals	521	210	40.3
Birds	1,193	251	21.0
Reptiles	685	391	57.1
Amphibians	460	307	66.7

Source: CCAD (2003)

In addition to the importance of its terrestrial ecosystems, Central America also possesses important freshwater and marine ecosystems, accounting for 8% of the world's mangrove forests and the second largest coral reef barrier in the world (CCAD, 2003). The region includes 12% of the coastlines of Latin America and the Caribbean and includes 576,000 hectares of mangroves, 1,600 km of coral reefs and 237,000 km² of the continental platform (CCAD, 2003).

Considerable effort has been made to conserve biodiversity within the region through the establishment of protected areas, biological reserves, or other protected categories. The Central American System of Protected areas (SICAP) currently includes 554 protected areas covering 129,640 km², which represents 25% of its area (Table 2; CCAD, 2003), and some individual countries such as Costa Rica, Guatemala and Panama have more than 25% of their territory officially protected (CCAD, 2003). In addition, many of the Central American countries have proposed additional protected areas that are awaiting official recognition.

Table 2. Summary of the number and area of protected areas in the Central American System of Protected Areas (SICAP), by country.

Country	# protected areas	% protected areas of SICAP	Extension (thousands ha)	% of the surface of SICAP	Territory of the country (thousands ha)	% of the territory of the country
Belize	74	13.4	1,071	8.26	2,280	47.21
Costa Rica	155	30.0	1,288	9.94	5,106	25.21
El Salvador	3	0.5	7,110	0.54	2,072	0.33
Guatemala	120	21.7	3,193	24.63	10,843	29.4
Honduras*	76	13.7	2,220	17.13	11,189	19.7
Nicaragua	76	13.7	2,242	17.30	12,140	17.0
Panama	50	9.0	2,941	22.66	7,443	26.0
Central America	554	100	12,964	100	51,073	25.0

Sources: CCAD (2003), IUCN (2003).

Despite the encouraging number of protected areas, the current network of protected areas has not been able to stem the current loss of biodiversity in the region. First, most of the protected areas are small and may not be able to conserve ecological processes and viable species populations, nor be able to withstand periodic, large-scale disturbances and long-term changes (Dinerstein *et al.*, 1995). According to data from 507 of the 554 SICAP protected areas, 69% are less than 10,000 ha in size (below the recommended size limit of the IUCN for a protected area to guarantee the long-term survival of their plant and animal communities and ecological processes) and 19% were between 5,000 and 10,000 ha (CCAD, 2003). Only 12% of the protected areas are larger than 50,000 ha. The largest protected areas in the region are the Reserva de Hombre y la Biosfera Río Plátano in Honduras (829,775 ha); other protected areas that have more than 500,000 ha include the Reserva Biosfera Maya in Guatemala, Reserva de la Biosfera Bosawas in Nicaragua, the Darién National Park in Panama and the La Amistad National Park in Costa Rica and Panama.

In addition to the limitations imposed by the size of protected areas, another critical problem is that not all ecoregions and their biodiversity are adequately represented within the existing protected area system (CCAD, 2003; PROARCA, 2003). Throughout the region, most protected areas have been established in mountainous

regions (usually above 1000 m) which were unsuitable for farming or inaccessible, or in the swampy lowlands; few protected areas occur in the fertile valleys or main agricultural regions (Powell *et al.*, 2000; Sánchez-Azofeifa *et al.* 2001). Consequently, only a handful of ecoregions are well represented in the protected area system (Table 3).

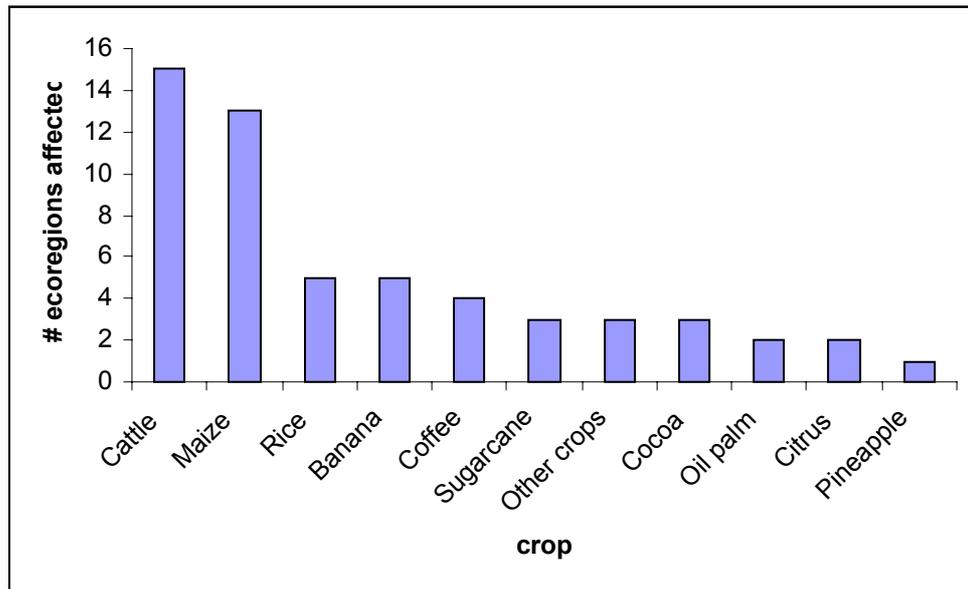
Table 3. Summary of the ecoregions that are best represented, or least represented in the National Parks System in Central America.

Best represented	Least represented
Petén Tropical Wet Forest, Guatemala	Sierra Madre Moist Forest (Guatemala, El Salvador)
Central American Caribbean Wet Forests (Honduras, Nicaragua and Costa Rica)	Central American Montane Forests (Guatemala, El Salvador, Honduras, Nicaragua)
Talamancan Tropical Wet Forest (Costa Rica and Panama)	Costa Rican Seasonal Moist Forests (Nicoya, Costa Rica)
Mixed Pine-Oak Forests (Guatemala and Honduras)	Monte Seco de Nenton, Guatemala
Belizean Pine Forests (Guatemala and Belize)	Panamanian Dry Forests
Chirripó Paramo, Costa Rica	Pine Forests on Bahia Islands, Honduras
Flooded Forests in Petén, Guatemala	Savannahs of Petén, Guatemala
Forests in the Darién, Panama	Cuchumatanes Paramo, Guatemala
Caribbean Mangroves in Honduras, Nicaragua, Costa Rica, and Panama	Motagua Valley Thornscrub, Guatemala

Source: PROARCA 2003.

A final and major problem of the current protected areas system is that despite their legal designations as protected areas, many of the protected areas are currently threatened by agricultural encroachment, illegal logging, hunting of wildlife, squatters, water contamination, and fires to name just a few problems (Carillo and Vaughan, 1994; Brandon *et al.*, 1998; Carillo *et al.*, 2000). Lacking sufficient resources and infrastructure (and sometimes the legal authority) to prevent these activities, many of the parks in the regions are being reduced to small degraded areas and are of little conservation value (CCAD, 2003).

a)



b)

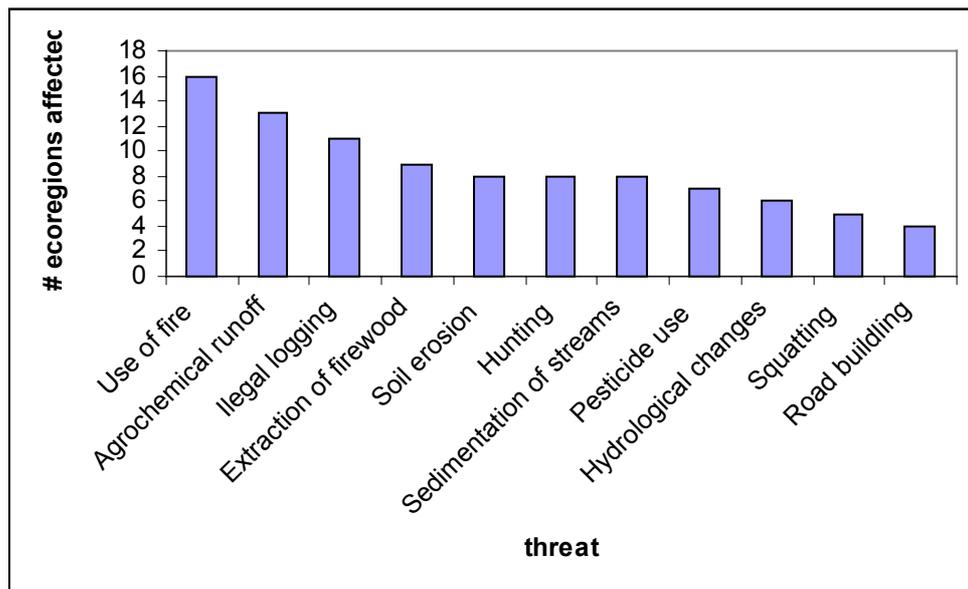


Figure 1. Summary of the number of ecoregions in Central America affected by different production systems (a) and by different activities related to agriculture (b). Data are based on Dinerstein *et al.* (1995) and additional surveys of experts of the threats facing the 23 ecoregions in Central America. Full details of individual threats per ecoregion can be found in Appendix 4.

Agricultural expansion into protected areas is a particular threat to conservation efforts. In a review of the conservation status of the 24 ecoregions in Central America, Dinerstein *et al.* (1995) note that the expansion of agriculture is actively contributing to biodiversity loss in at least half of the ecoregions in Central America and that most

ecoregions are threatened by logging, agricultural fires, soil erosion, pesticide use and hunting, that accompany agriculture, and to a lesser degree by sedimentation of streams, hydrological changes, road building, firewood extraction and squatting (Figure 1; a summary of individual threats per ecosystem is found in Appendix 4). Of these 24 ecoregions, only 7 are considered to be relatively stable and unthreatened (Appendix 3). Another limitation of the current protected areas system is that many protected areas are isolated in agricultural matrices that can impede animal movement and disrupt ecological processes, such as gene flow, pollination, seed dispersal, and migration (Janzen, 1983; Powell *et al.* 2002). Although it is not exactly clear how many plant and animal species are threatened by these activities, the IUCN list of threatened species ranges from 37 to 195 per country (Table 4), and it is likely that the actual numbers are much higher.

Table 4. Total number of threatened species per taxonomic group for Central America by country.

Country	Mammals	Birds	Reptiles	Amphibians	Fishes	Mollusks	Other Invertebrates	Plants	Total
Belize	5	2	4	0	17	0	1	30	59
Costa Rica	13	13	7	1	13	0	9	110	166
El Salvador	2	0	4	0	5	0	1	25	37
Guatemala	7	6	8	0	14	2	6	85	128
Honduras	10	5	6	0	14	0	2	111	148
Nicaragua	6	5	7	0	17	2	0	39	76
Panama	17	16	7	0	17	0	2	195	254

Source: IUCN (2003)

Agriculture in Central America

Throughout Central America, agriculture has traditionally been (and continues to be) an important economic activity, generating employment and income for a significant proportion of the population, and serving as a key source of foreign income. The production of export commodities, such as coffee, bananas, sugarcane and beef, has been a key driver of economic development in the region, and much of the region's history is intricately linked to the expansion of these commodities (Utting, 1996). Although the economic importance of agriculture has declined in recent decades in all Central American countries except Nicaragua, agriculture still remains an important economic activity, contributing an estimated 7.1 to 36% of the total gross domestic

product per country (Table 5). The actual importance of agriculture in the region, however, is probably higher than that reflected in these statistics, as these values do not include the additional value generated by the processing, packaging and marketing of agricultural products, which are associated with the food and agroindustrial sectors. For example, in Costa Rica it is estimated that if these additional values were included, the contribution of agriculture to the gross internal product would be three times greater than the value currently reported (IICA, 2003).

Table 5. Economic indicators of the importance of agriculture (including crops and livestock) in Central American countries, from 1990 to 2000. N/a indicates data not available.

Country	GDP per capita (US\$) 2000	Agriculture as % of total GDP		Agricultural exports as % of total exports of goods		Annual growth of total GDP 1995-2000 (%)	Annual growth of agriculture and livestock GDP 1995-2000 (%)
		1990	2000	1990	2000		
Belize	N/a	N/a	N/a	77.7	69.4	N/a	N/a
Costa Rica	3948	12.7	11.6	58.8	30.8	5.0	3.2
El Salvador	2104	16.5	12.0	55.5	41.1	2.9	1.3
Guatemala	1680	23.0	20.2	71.3	58.4	3.8	2.8
Honduras	909	20.5	18.7	69.8	51.2	3.0	1.0
Nicaragua	472	30.8	36.0	73.7	64.8	5.3	6.9
Panama	3508	8.9	7.1	58.9	41.8	3.6	1.4

Sources: CEPAL (2002), Hertford and Echeverri (2003), Proyecto Estado de la Región (2003).

In economic terms, the most important agricultural commodities in the region are bananas, coffee sugarcane and tropical fruits, which accounted for 9.8, 8.4, 3.2 and 1.4 percent respectively of the total goods exported to the Common Central American Market in 2001 (Table 6). However, in terms of total land area occupied, the dominant agricultural land use is pasture for cattle raising which accounts for 13 to 45 per cent of the land use per country. The importance of other agricultural systems varies across the Central American countries (Figure 2; See Appendix 5 for details on the area dedicated to different agricultural crops and pastures in each country). For example, basic grains (i.e. rice, maize, beans, sorghum, etc.) are the second-most common agricultural land use (after pastures) in El Salvador, Guatemala, Nicaragua and Honduras, whereas in Costa Rica, Belize and Panama no single agricultural crop dominates.

Table 6. Relative importance (in %) of main agricultural products in relation to total exports of goods for the Common Central American Market (includes Costa Rica, El Salvador, Guatemala, Honduras, and Nicaragua; data from ECLAC, 2003). Dashes indicate values of << 0.05%.

Agricultural commodity	1985	1990	1995	1996	1997	1998	1999	2000	2001
Bananas	14.2	16.2	14.4	12.8	10.1	10.1	7.3	7.4	9
Coffee	37.5	26	24.5	19	20.4	17.3	13	14.6	8.4
Sugar	5.5	5.5	4.5	3.2	3.7	3.8	2.1	2.1	3.2
Tropical fruits (excluding bananas)	-	-	1.1	0.9	1.1	1.3	1.2	1.1	1.4
Meat	2.3	4.3	1.3	-	-	-	-	-	-
Total exports of goods (millions of US\$)	3,506	3,924	7,339	8,440	9,708	11,075	11,578	11,479	10,185

Source: ECLAC (2003).

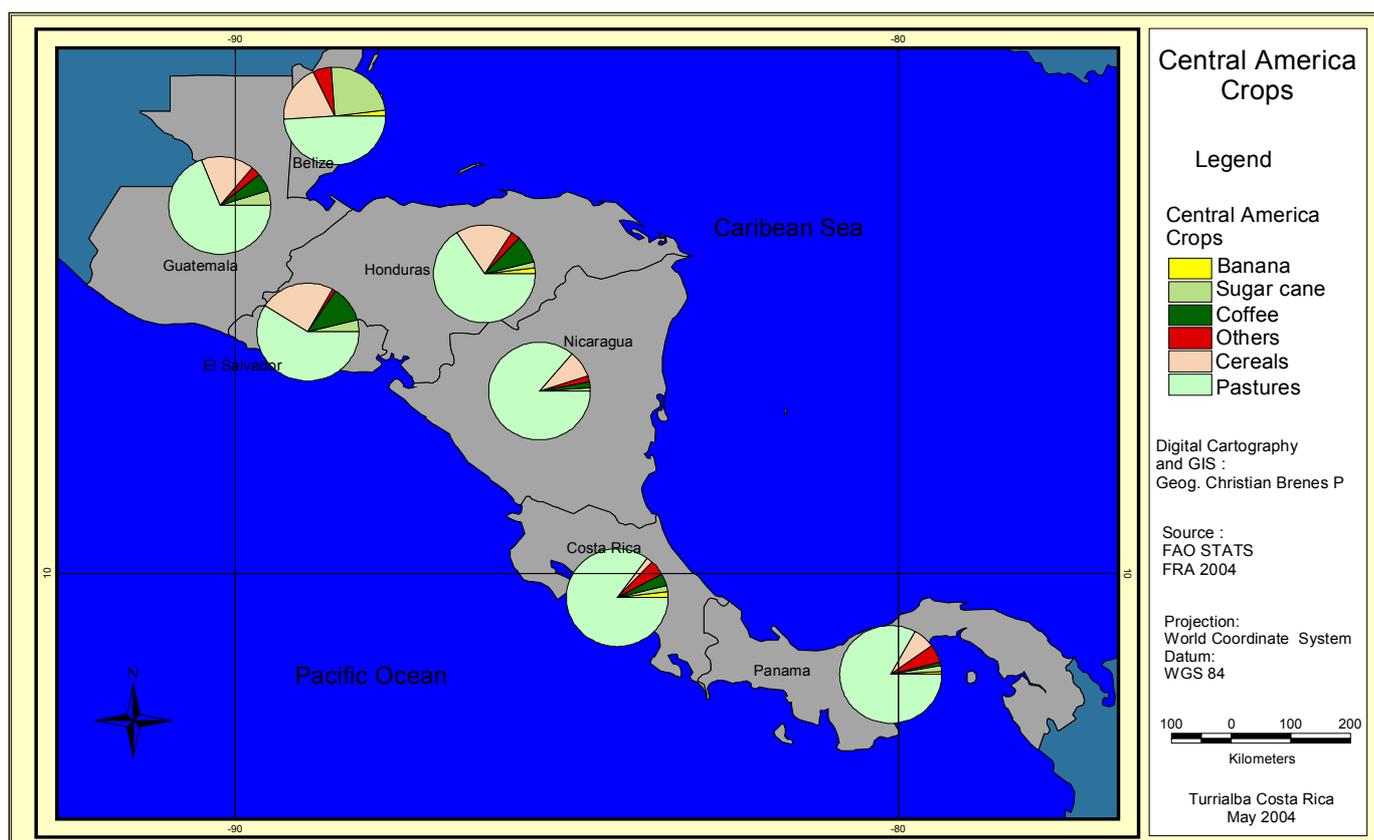


Figure 2. Map showing the percent land under different agricultural systems in each of the Central American countries. Sources: FAOSTAT (2004), FRA (2000).

Due to its varied topography, soil types and climates, Central America has a wide diversity of agricultural production systems. These systems vary not only in the agricultural crops cultivated or the animals raised, but also in the plot or farm sizes, types and intensities of management, arrangement in the landscape, orientation for export or internal markets and agroecological conditions, as well as where they are located within the Central American isthmus (Table 7). However, in general the main systems can be categorized in the following broad classes (ICCO, 1997; Baumeister, 2003): 1) large agroindustrial plantations (sugarcane, banana, African oil palm, citrus, pineapple and other fruits); 2) small and medium plantations of coffee and cocoa; 3) medium and large plantations of fruits and vegetables which are integrated into market chains for processing and packaging; 4) large industrial farms dedicated to the cultivation of basic grains (rice, maize and beans); 5) intensive production systems of chickens, pigs and dairy cattle; 6) small farms dedicated to the production of basic grains, small livestock, vegetables for internal markets; and 7) large and medium extensive cattle producers.

Table 7. Characterization of the main crops and types of agricultural systems in Central America.

Agricultural crop	Type of agricultural system (based on description on p15)	Size of production area	Orientation (export, local markets, or subsistence)	Monoculture (M) or polyculture (P)?	Climatic conditions required					Isthmian location
					Altitude msnm	Temperature Minimum-maximum ° C	Soils	Precipitation mm/year	Topography	
Oil palm	1	Very large farms (>1,000 ha)	Export	M	0-300	17° - 28°	Alluvial loamy soils, well drained	2,000 or more	Flat lands to lightly undulating	Pacific coast
Banana	1	Generally >80 ha	Export	M	0-300	21° - 29.5°	Alluvial soils	1,000 - 4,500	Flat lands	Atlantic and Pacific coasts
Vegetables	3	Usually <1 ha	Local	M	N/a	N/a	Well drained soils with and high organic material	N/a	N/a	Depends on the crop, but generally planted in high hillsides
Coffee	2	Generally 5-20 ha, with exception of some large producers	Export	M or P	600-1,650	13° - 27°	Soils derived from volcanic ashes and alluvial deposits	1,000 - 2,300	Flat lands and/or undulating	Mainly in mountainous areas, but also found in coastal zones on hills >600 masl
Cocoa	2	Generally small areas <5 ha	Export	M or P	0- 1,000	15° - 25° or more	Well drained soils	1,500 - 2,500	Flat lands	Atlantic coast
Maize	4,6	Generally small and medium, some large farmer with >50 ha	Subsistence/ local	M or P (often intercropped with beans and squash)	0-2000	18° - 28°	Sandy loam to clay loam	300 - 500	Flat and/or undulating land	Entire region
Rice	4,6	Variable	Both export and local	M	0-850	18° - 35°	Clay – sandy, loam, clay, sandy	5-10 mm/day	Flat lands	Pacific and Atlantic coasts
Sugarcane	1	Mostly medium-large	Export	M	1,500-3,500	27° - 32°	Loam, loam, clay	N/a	Flat lands	Pacific coast
Cattle	5,6,7	Beef: medium-large Dairy: small-medium	Export (some local)	M	0-2,000	N/a	All soil types	N/a	Flat and/or undulating land	Beef production on Pacific and Atlantic coasts; Dairy production primarily in central mountainous region

Sources: Monge (1980, 1989); Cortés (1994)

Overview of tendencies in Central American agriculture

There are three main tendencies in Central American agriculture which affect biodiversity conservation: 1) the expansion of the agricultural frontier into previously forested areas, 2) the intensification of agricultural production through enhanced use of purchased inputs (pesticides, fertilizers, manufactured seeds, and machinery per unit land), and 3) changes in the configuration of agricultural landscapes due to the rotation or replacement of different agricultural systems in the landscape. Historically, the expansion of the agricultural frontier has been the main driver of biodiversity loss as farmers have looked to expansion rather than intensification as a means to increase production, however, as available land becomes scarce, the problem of intensification of agricultural practices (and resulting changes in the agricultural landscape) is likely to become more important.

The three tendencies in Central American agriculture, in turn, stem from a complex interaction of driving sources of forces (sources of stress) that include (but are not limited to) demographic and social factors, poverty levels, land distribution and land tenure patterns, governmental policies and laws, international prices and markets for agricultural products, expansion of infrastructure, market failures, technological advances, biophysical factors and free trade agreements. Each of these factors may affect the rate of deforestation and agricultural encroachment, intensification levels or changes in the landscape either individually or in combination with other forces (Figure 3). In the following subsections, we consider in greater detail the ongoing changes in Central American agriculture, as well as the factors that drive them. Due to the large number of factors affecting these patterns and the complexity of interactions amongst them, we discuss factors individually; however in any particular site, a number of these factors are likely to occur simultaneously, with possibilities for synergisms or feedbacks.

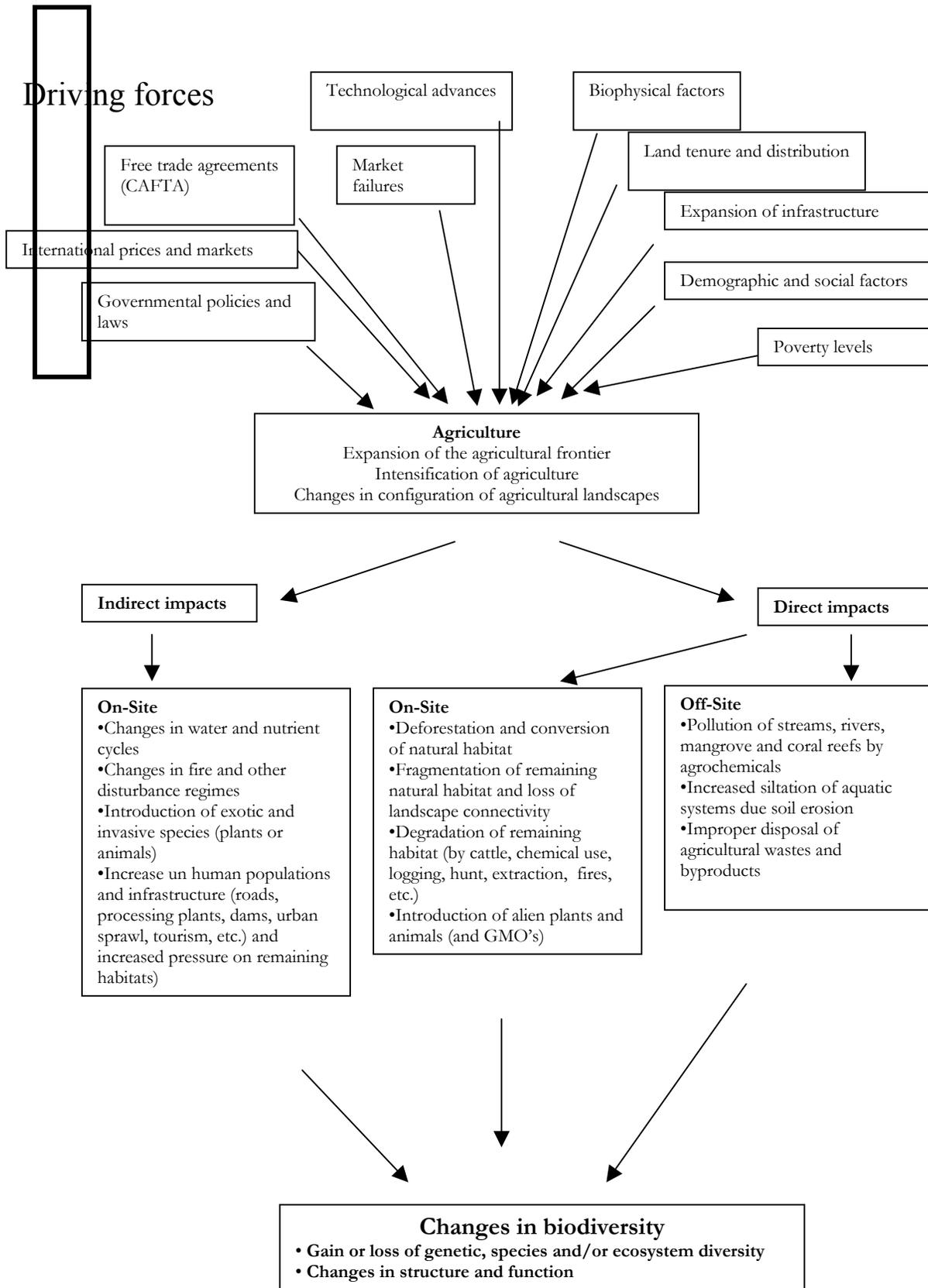


Figure 3. Conceptual framework of the factors affecting changes in agriculture and the impacts of agriculture on biodiversity.

Dynamics of the agricultural frontier

One of the main tendencies in Central American agriculture has been the rapid advance of the agricultural frontier at the expense of the region's forests. During the 1900's (and particularly after World War II), the agricultural frontier advanced very rapidly, replacing forest at an alarming rate (Kaimowitz, 1996; Kaimowitz and Paupitz, 1999). Over the past 4 decades, forest loss in Central America has ranged from 340,000 ha per year to 431,000 ha, when deforestation peaked in 1981-1985 (Humphries, 1998). Currently, it is estimated that the remaining forest cover in Central America is limited to 17 to 19 million ha (or roughly 20% of the total land area), most of which is broadleaf forest located at the Atlantic side of the isthmus¹. There are also important areas of pine forests remaining in the central mountainous regions of Honduras, Nicaragua and Guatemala, as well as heavily threatened mangrove forest in the coastal areas (Kaimowitz and Paupitz, 1999).

Agricultural expansion first affected the Pacific lowlands, where the drier climate and flat lands facilitated the conversion of forest to agriculture, and subsequently moved to the cooler highlands with rich, volcanic soils. However, as these areas were deforested and land became scarce, agriculture gradually expanded across to the Atlantic region, so that today all areas of the isthmus face pressure from agriculture. Active agricultural expansion continues on the Atlantic side of Central America (particularly in the Petén in Guatemala, the regions of Olancho, El Paraíso, Colón, Gracias a Díos and Atlantida in Honduras, the Atlantic region of Nicaragua, and the area of Colón, Bocas del Toro and Darien in Panama; Pasos, 1994). In contrast, the agricultural frontiers in El Salvador and Costa Rica have disappeared as the remaining forest has already been claimed or has been designated as protected areas. Unless corrective actions are taken, it is estimated that the expansion of the remaining agricultural frontiers will come to a close within two or three decades, as the available areas of natural ecosystems are exhausted (Baumeister, 2003; Pasos, 1994).

¹ Remaining forest occurs primarily in the Petén of Guatemala and Belize; Colón, Olando Este and Gracias a Dios in Honduras; Jinotega, Rio San Juan and the Autonomous regions of the North and South Atlantic (RAAN and RAAS) in Nicaragua, Limon in Costa Rica, and Bocas del Toro and Darién in Panama).

The internal dynamics of the expansion of the agricultural frontier are quite complex, varying with the particular socioeconomic and biophysical contexts of a given site. However, the general pattern of expansion starts with the clearing and burning of the existing forest, followed by a few years of shifting agricultural production (generally of basic grains such as maize, beans or rice) for subsistence, though a few small and medium sized farmers may also sell some of their products on local markets. After a few years, the soils are no longer productive, and farmers either convert their land to pasture, sell it to larger cattle ranchers, or leave it in fallows (PROARCA, 1998; Mejía Valdivieso, 2001; Smith *et al.* 2001). The colonists then move on to new places and the process starts again. In some cases, the colonists establish relatively stable colonies, however in most cases, they fall into a cycle of poverty and emigration to new lands (Pasos, 1994; Thrupp *et al.* 1997). Although there is no scientific study that has demonstrated which factors contribute to the failure or success of new colonies, relevant factors might include the type of soils, climatic conditions, the crops initially planted after land clearing, the composition of the pioneer group (stable or highly conflictive) and state policies towards these activities (Pasos, 1994).

There are currently three types of agricultural frontiers in Central America- frontiers in indigenous reserves, frontiers that arise spontaneously and frontiers that are actively promoted by governments (Pasos, 1994). In the indigenous frontiers, the settlers usually have a common cultural identity and social organization, ancestral knowledge of forest resources, low population densities, diversified production systems and a common property approach to land use, which result in agricultural landscapes that have a more heterogeneous mix of land uses, including many types of agroforestry systems. In contrast, in the spontaneous pioneer fronts, settlers are generally motivated by land speculation and clear the land rapidly in order to ‘improve’ it and sell it later at a profit. In Central America, this pattern has been repeated many times, as settlers from the Pacific region move to the Atlantic region, where lands are still available, in a mad rush to gain land. These agricultural settlers form generally a very heterogeneous group, though poverty is often a common denominator. The final type of agricultural frontiers are those where the national government actively promotes, and even organizes, the process of colonization, designating areas for colonization and criteria for land acquisition. This type of practice was very

common in Costa Rica (where the former ITCO and today's IDA actively distributed land among the landless), but has also been observed in Honduras and in Nicaragua (during the Somoza administration in the 1970's).

Despite differences in the types and dynamics of individual agricultural frontier, the expansion of agricultural frontier at all sites is closely linked to the export cycles of Central American's main agricultural commodities- coffee, bananas and livestock- and the current patterns of land use largely reflect the histories of these three commodities (Pasos, 1994; Utting, 1996). Coffee production was largely responsible for activating the expansion of the agricultural frontier in Central America and dramatically transforming landscapes, particularly in the highlands (Pasos, 1994; Somarriba *et al.* 2004). In the mid seventies, high international prices for coffee stimulated its expansion into areas that were previously considered marginal due to poor access to soil resources (Pasos, 1994).

Similarly, the introduction of banana plantations was largely responsible for driving agricultural development in the Caribbean. The spread of banana plantations into the Caribbean lowlands was facilitated by the construction of the roads and railways required to bring coffee exports to the Caribbean coast, as well as the influx of foreign investment capital and the fact that these areas were situated in marginal regions far away from state control (Pasos, 1994). Most of the land dedicated to banana plantations was previously considered of low quality and was seasonally under water, but the introduction of a profitable crop created land speculation and increased incentives for land clearing in areas adjacent to already established plantations (CCAD, 1998; Pasos, 1994). As large-scale banana plantations were established, subsistence farmers and indigenous settlements were displaced to more mountainous regions, stimulating new agricultural frontiers. For example, when the Chiriquí Land Company established large banana plantations in southern Costa Rica, it displaced the indigenous settlements (and agricultural activities) towards areas with high slopes in the Talamanca Mountain Range, and increased deforestation in these areas.

However, the most important land use change in the last 40 years in Latin America has been the clearing of forest in favor of pasture land for livestock production, with the total area in pasture increasing from roughly 3.5 million ha in 1950 to more 13 million ha in 2001, and affecting all countries in the region (Table 8; Blackburn and De Haan, 1999). Pasture establishment on deforested areas can occur as a result of three basic strategies- a direct strategy whereby livestock producers pay their employees to cut the forest areas on previously established farms, an indirect strategy in which large livestock producers encourage the invasion of forested land by pioneers, allow them to use it for a few years in subsistence agriculture before leaving it to the cattle rancher, or as a result of small farmers clearing the land for agriculture but gradually converting it to pasture before selling or losing it to a large ranch (ICCO, 1997; Kaimowitz, 1996; Serrao and Toledo, 1992).

The expansion of pasture lands in Central America since 1950 has followed different stages, affecting almost all regions within the isthmus. From 1950 to 1979, 60% of new pasture land was located on the Pacific coasts and central regions, where fire could easily be used to clear the land, due to high temperatures and low precipitation (Kaimowitz, 1996). However, at beginning of the 1980s, cattle production began to move towards the Caribbean coast following the availability of land and quickly became the main driver of deforestation of humid tropical forest in this region (Kaimowitz, 1996; CCAD, 1998; PROARCA, 1998). In recent years the rate of pasture expansion has begun to stabilize, as available land for expansion is now extremely limited, international demand for meat has decreased and governmental incentives for cattle production have been reduced. However some deforestation for pasture establishment continues in areas where armed conflicts have recently ended and where agrarian reforms have been implemented, such as the central and northern areas of Nicaragua (Kaimowitz and Paupitz, 1999).

Table 8. Evolution of permanent pasture in Central America from 1961 to 2001.

Area under permanent pasture (1000 ha)	1961	1971	1981	1991	2001
Belize	37	37	44	49	50
Costa Rica	915	1,390	2,090	2,330	2,340
El Salvador	604	610	610	640	794
Guatemala	1,110	1,210	1,310	2,500	2,602
Honduras	1,500	1,500	1,500	1,500	1,508
Nicaragua	3,900	4,400	4,815	4,815	4,815
Panama	1,060	1,170	1,320	1,480	1,535
Total	9,126	10,317	11,689	13,314	13,644

Source: FAOSTAT (2004).

Dynamics of the intensification of agricultural practices in Central América

A second key trend in Central America is the intensification of agriculture through the increased use of pesticides, fertilizers, manufactured seeds and varieties, and machinery per unit of land already dedicated to agriculture (Lesser and Kyle, 1996, Burinsma, 2003). As agriculture has become more and more oriented towards cash crops for export, the use of pesticides, herbicides and other chemical inputs has accelerated at an alarming rate and become widespread (Kammerbauer and Moncada, 1998). Pesticides were first introduced into Central America in the late 1940's and were quickly adopted by farmers: by 1970 their use was widespread, with Costa Rica importing 5.8 million kg of pesticides, and Guatemala and Nicaragua each importing more than 8.5 million kg of pesticides (primarily for use in cotton plantations; Castillo *et al.*, 1997). In most countries, this rapid increase in the use of fungicides, herbicides and insecticides continues even today (Figure 4). Specific details on the amounts of insecticides, herbicides and fungicides imported per country can be found in Appendix 6.

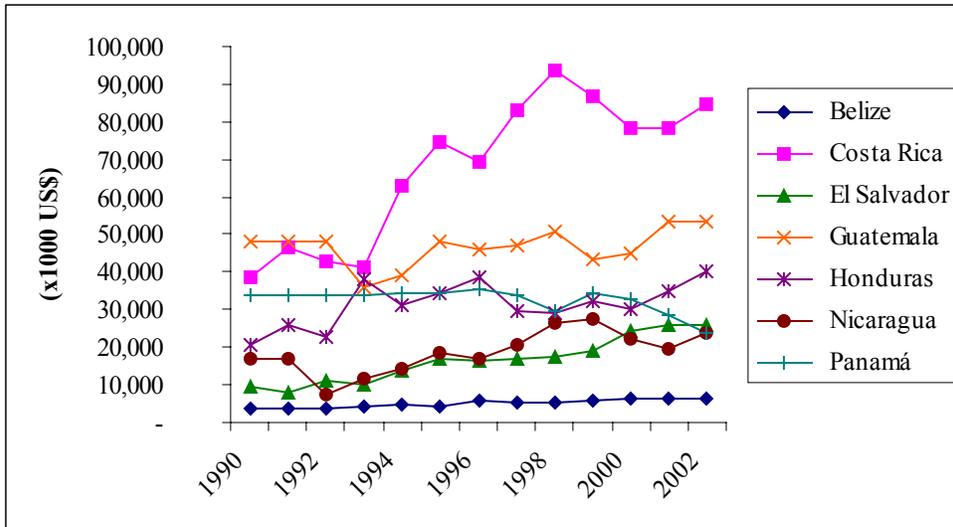


Figure 4. Comparison of the total import value of fungicides, herbicides and insecticides in Central America from 1990 to 2003 (based on FAOSTAT, 2004).

Although agrochemicals are used in almost all agricultural systems, production systems that are orientated towards export tend to use larger quantities of fungicides, herbicides and insecticides than those that are for subsistence or local consumption. In Guatemala, for example, studies have shown the production of vegetables for export uses 6 to 7 times more pesticides than maize production (ICCO, 1997). In Costa Rica, 30% of imported pesticides are used in the banana plantations (Castillo *et al.* 2000). Other systems that use high levels of pesticides in Costa Rica include coffee and sugarcane (Castillo *et al.*, 1997; Ulloa *et al.*, 2004). Cotton plantations, which were once very common in parts of Central America, also traditionally used very high pesticide levels, and spray from these plantations is thought to have affected neighboring agricultural systems, as evidenced by high levels of pesticides present in milk in dairy cows near plantations in Nicaragua and Guatemala (ICAITI, 1977, cited in Pretty, 1995). In Honduras, most pesticides are used in banana plantations, coffee plantations, vegetables, maize, rice and bean crops, with an estimated pesticide load of 1.3 kg/ha of cropland per year (Kammerbauer and Moncada, 1998). Although it is difficult to obtain clear data on the amount and frequency of pesticide use per cropping system and per country due to the lack of data and publications on pesticide use in the region, the available data indicate that pesticide use is widespread and rapidly increasing (García, 1997; Reiche, 1997; Kammerbauer and Moncada, 1998; Klemens *et al.*, 2003).

Another sign of the increasing intensification of agriculture in Central America is the high fertilizer use, particularly in crops produced for export. Fertilizer use in the region is highly variable across countries, with Costa Rica, Honduras and Guatemala having a much higher total consumption than the other countries (Figure 5). However, overall levels of fertilizer application are quite high (with an overall mean of 217 pounds of fertilizer per ha of cultivated land; Hertford and Echeverri, 2003) and the region is highly dependent on fertilizers to increase soil productivity.

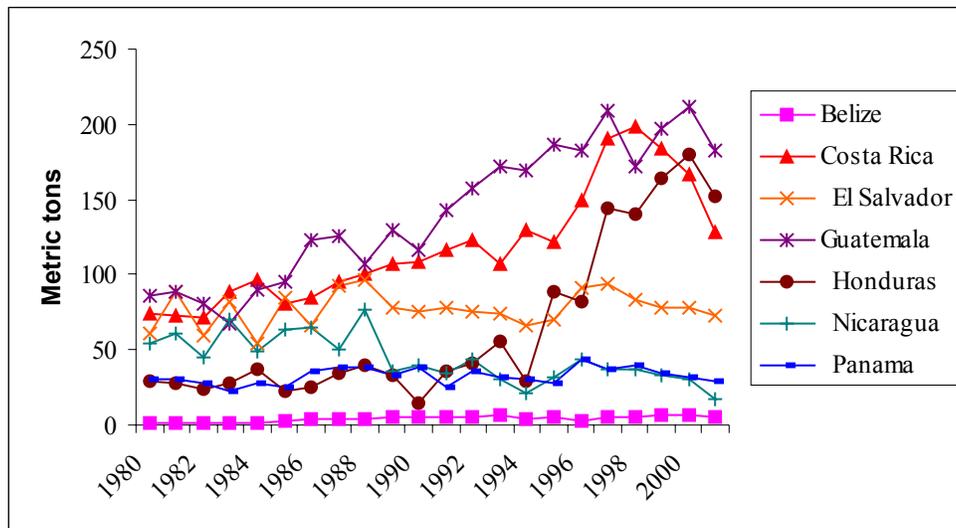


Figure 5. Total annual consumption of fertilizers in Central American countries from 1980 to 2002. Source: FAOSTAT (2004).

Another indication of the tendency towards more intensified production is the slow increase in number of tractors. In 1961, Central America had an average of 2.4 tractors per 1000 hectares of planted land; by 1996 this number had doubled to 5.8 tractors (Hertford and Echeverri, 2003). However, overall capital investment in the region is highly variable across the region. For example, Costa Rica, the most capital intensive of the Central American countries had one tractor per 72 hectares in 2000, whereas Nicaragua averaged one tractor per 1017 ha, an abysmal difference for the two neighboring countries (CEPAL, 2003).

A final important tendency is the increased use of high-yielding plant varieties, improved seed and improved cattle breeds, all of which generally result in higher productivity, but also require increased external inputs (McNeely and Scherr, 2000; Clay, 2004)

Dynamics of changing landscapes in Central America

A final characteristic of Central American agricultural landscapes is their dynamic nature. Agricultural landscapes are generally complex mosaics of patches of different type, size, shape and arrangement, and these patterns may change over time due to both natural and human processes (Anderson, 2001; Veldkamp and Fresco, 1997). For example, landscapes may change as different patches move in and out of different uses as new land is cleared, degraded lands are abandoned to fallow, market factors drive changes in cropping patterns, or large farms or fields are subdivided into smaller units (or vice versa). These changes in land use patterns may be very rapid, with entire landscapes changing over the period of just a few years, or occur more gradually. For example, the landscape surrounding the La Selva biological station in Sarapiquí, Costa Rica changed from a forested landscape with small subsistence farms (with rice, beans, maize, bananas, coffee and pork production) in the 1950's, to a landscape with increasing areas of rice farms between 1952 to 1960, to a landscape dominated by banana plantations in the 1960's and 1970's, and the spread of cattle production from the 1970's onwards (Butterfield, 1994). Regardless of how they occur, these changes in landscape structure and composition may have important consequences for both patterns of biodiversity and ecological processes (e.g., Logsdon *et al.*, 2001; Turner *et al.* 2001).

In Central America, one of the main changes in agricultural landscapes has been the types of crops and land uses present, due to the boom (and often subsequent collapse) of key crops such as cotton and cocoa. Due to a high international demand for cotton in the 1950s, many large areas previously occupied by other crops or natural forest cover were cleared and converted into cotton plantations, particularly on the Pacific coast of Guatemala, El Salvador and Nicaragua (Pasos, 1994). Cotton was produced in large plantations based on intensive soil use, high agrochemical use and high employment of landless farmers.

However, when the price of cotton collapsed in the 1980's, creating widespread poverty and migration to urban areas (Pasos, 1994), the lands previously dedicated to cotton were converted to sugar cane plantations and other land uses (Baumeister, 2003). Similarly, the collapse of the cocoa sector in the 1980's (due to low prices combined with the arrival of new diseases which significantly reduced production) led to widespread abandonment of cocoa plantations and in some cases, their conversion to other land uses. Another important change has been the establishment of large-scale plantations of oil palm in land previously occupied by banana plantations (which were abandoned due to reductions in banana prices and problems with disease). In Tela, Honduras and Parrita, Costa Rica, for example, this new industry made good use of the infrastructure left behind by banana producers (CCAD, 1998). A rapid overview of the broad trends in the changes of area under different crops over the last 40 years is presented in Figure 6.

Significant changes in landscape composition may also occur when the locations (but not necessarily the total area) of individual crops change. A good example of this is the regional distribution of grain production. Although the area planted with basic grains in Central America in 1978 (2.4 million hectares) is basically the same as in 2001 (2.5 million hectares), the location of this production has changed. Whereas basic grains were previously cultivated throughout the region, subsistence farmers have increasingly been forced to move into hillsides and areas of low soil fertility, as larger farms and companies devoted to production of export crops now occupy the prime agricultural lands in the lowlands.

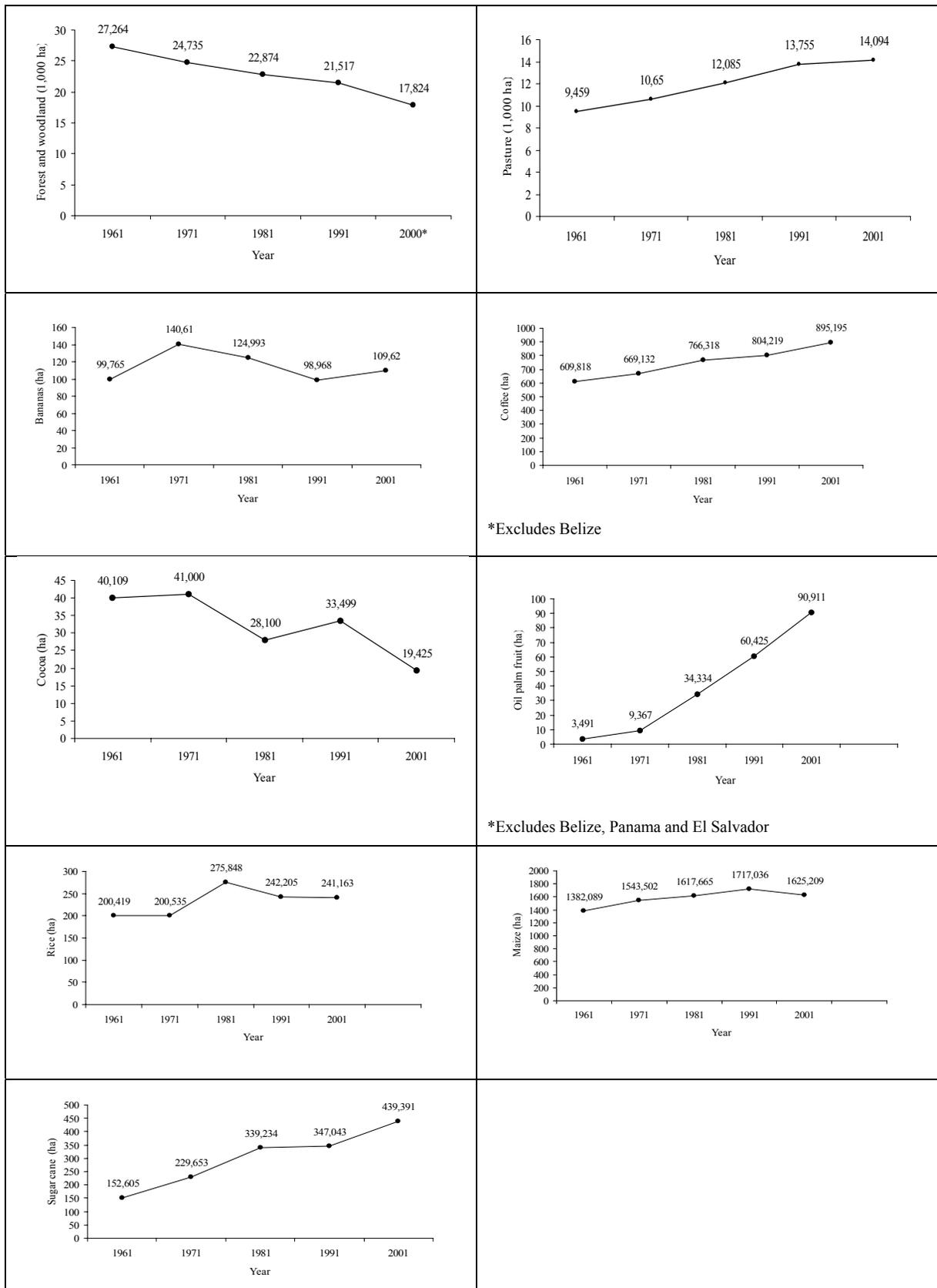


Figure 6. Dynamics of land use dedicated to forest and agricultural activities (pasture, banana, coffee, cocoa, oil palm, rice, maize and sugarcane) in Central America, from 1961 to 2000/2002. Agricultural data stem from FAOSTAT (2004) whereas forest data stem from FAO (2003).

Another important feature of agricultural landscapes is that the forest and tree cover they retain can be highly dynamic. In addition to the obvious changes due to continued deforestation and fragmentation, farm tree cover can decrease over time due to harvesting for timber and firewood, as well as due to the natural death of remnant trees and limited natural regeneration (Harvey and Haber, 2000; Harvey *et al.*, 2004). On the other hand, farmers may also increase the amount of tree cover remaining in their landscapes by actively planting windbreaks, forest plantations, live fences or trees, abandoning areas to fallow, or allow natural regeneration to occur. While these changes in tree cover are often subtle and occur at a fine spatial scale, the collective effect of changes on multiple farms can be considerable, as witnessed in the sudden expansion of secondary forests in Guanacaste, Costa Rica as farmers abandoned degraded areas due to low cattle prices and as reforestation programs were initiated (Janzen, 1986).

A final potential change in the structure and composition of landscapes is due to changes in management that may result in changes in the size and distribution of patches of different land use or in the complexity of their shapes. For example, as cattle producers move from extensive to intensive production, they often subdivide their pastures into smaller units (to facilitate cattle rotation), plant live fences to divide paddocks, and reduce the dispersed trees within their pastures, and this greatly reduces the patch size and type of tree cover present within the landscape (Villacis, 2004). The conglomeration of many small farms into a few larger farms may result in a less diverse landscape with fewer and larger elements; conversely the diversification of farms with new crops or polycultural systems may create more heterogeneous landscapes of many smaller elements with more complex shapes.

Underlying factors affecting agricultural activities in Central America

A large number of factors affect agricultural activities in Central America and drive the three major agricultural tendencies discussed earlier, namely the expansion of the agricultural frontier, intensification of current agricultural practices and changes in the composition of agricultural landscapes. These factors include (but are not limited to) demographic and social factors, poverty levels, land distribution and land tenure patterns,

governmental policies and laws, international prices and markets for agricultural products, expansion of infrastructure, market failures, technological advances, biophysical factors and free trade agreements. Each of these factors may affect the rate of deforestation and agricultural encroachment, the intensification of existing agricultural lands or changes in the landscape either individually or in combination with other forces (Figure 3), however, the particular way in which a given factor may affect agriculture in a particular landscape is often difficult to predict. For example, increased beef prices in international markets create incentives not only to expand into new areas, but also make a more intense use of the already available pastures, and these changes in management bring about changes in the structure and composition of landscapes in cattle regions.

In the following sections, we identify the main factors that have driven the expansion of the agricultural frontier, the increasing intensification of agriculture, and large-scale changes in agricultural landscapes. Due to the large number of factors affecting these patterns and the complexity of interactions amongst them, we discuss factors individually; however in any particular site, a number of these factors are likely to occur simultaneously, with possibilities for synergisms or feedbacks. Our analysis is based primarily on historical evidence, however it is likely that these factors will continue to place pressure on the use of the natural resource base in years to come.

Demographic and social factors

Central America is primarily an agricultural society and is heavily dependent on agriculture as a livelihood strategy, with just over half of its population living in rural areas and agricultural activities accounting for between 32 and 75% of the employment in rural areas in each country (Table 9). Although the region is undergoing a process of urbanization and concentration of the population in increasingly larger cities, it is likely that agriculture will continue to be an important activity for decades to come.

Population pressure in Central America has rapidly increased in the last decades, with a 300% increase since 1950 (Proyecto Estado de la Región, 1999). Currently the region has a population of 38 million inhabitants, of which 20% are indigenous. With an estimated

growth rate at 2.6% per year, the population is expected to double within the next 25 years (Proyecto Estado de la Región 1999; 2003; Hertford and Echeverri, 2003). This backdrop of a rapidly growing population, a high dependence on agriculture, a growing need for land, and an increased demand for firewood and other resources has contributed to the expansion of agriculture into marginal areas and is likely to continue to place pressure on both the remaining forests and agricultural land in future years.

Table 9. Summary of demographic characteristics of Central America. N/a indicates that data are not available.

	Population (x 1000) 2003	Population growth rate (%)		Rural pop. (% of total) 1998	Pop. density (#/km ²) 2003	Pop. using fuel wood for cooking (% of total) 2000	Agricultural employees in rural areas (% of total) 2002
		1990- 1995	1995- 2000				
Belize	273.7	N/a	N/a	51.2	9.7	N/a	N/a
Costa Rica	4,167.4	2.06	1.74	50.5	82	11.8	42
El Salvador	6,638.2	2.29	2.16	46.5	317	38.6	51
Guatemala	12,309.4	3.05	2.92	61.0	113	N/a	59
Honduras	7,001.1	3.10	2.81	53.7	62	N/a	75
Nicaragua	5,488.7	3.17	2.97	41.2	46	64.3	68
Panama	3,116.3	1.98	1.90	43.3	40	20.7	32
Central America	38,994.8	N/a	N/a	51.8	N/a	N/a	N/a

Sources: II Estado de la Región 2003, Baumeister 2003, Hertford and Echeverri (2003)

Poverty

The high levels of poverty in Central America (particularly in Honduras and Guatemala) are another factor driving patterns of deforestation and environmental degradation. Table 10 shows the daunting reality of the Central American region, where on average, 50% of the population in Central America is poor (i.e. unable to cover some basic needs such as nutrition or housing) and 23% is extremely poor (i.e. not able to cover even daily basic nutrition). Poverty levels are not homogenous across countries or across regions within the same countries. Particularly striking are the cases of Honduras and Guatemala, with poverty levels of 74.5% and 78.5%, respectively. In general, rural populations are poorer than their urban counterparts, with poverty affecting approximately 68% of those living in the rural

areas, and extreme poverty affecting 35% of the rural population. A striking example of this is the case of Panama, where 52.5% of the rural population is poor compared to only 11.1% in the urban areas.

Table 10. Comparison of poverty levels in urban and rural populations in Central America in 2001.

Level	% of total population						
	Costa Rica	El Salvador	Guatemala	Honduras	Nicaragua	Panama	Central America
Poverty ^a							
<i>Total</i>	22.9	45.5	56.2	71.6	45.8	40.5	50.8
<i>Urban areas</i>	18.6	35.3	27.1	63.4	30.1	23.4	33.6
<i>Rural areas</i>	28.5	59.9	74.5	78.5	67.8	68.9	67.9
Extreme poverty ^b							
<i>Total</i>	6.8	19.8	15.7	53.0	15.1	26.5	23.0
<i>Urban areas</i>	3.9	11.1	2.8	32.5	6.2	11.1	10.8
<i>Rural areas</i>	10.5	31.9	23.8	70.4	27.4	52.2	35.1

Source: Proyecto Estado de la Región (2003)

^{a/} Poverty: Unable to cover some basic needs, including nutrition, housing, etc.

^{b/} Extreme Poverty: Unable to cover basic daily nutrition

The prevalence of poverty has important consequences for natural resource management, as there is a well established vicious circle between increased poverty and environmental degradation (Dasgupta, 1993; Barraclough and Ghimire, 2000), though this relationship may be broken and overcome in some circumstances (Scherr, 2000). Poor individuals depend more heavily on the environment as a source of income, food, shelter, building material, etc. Consequently, increases in poverty tend to lead to increased pressure on the natural resource base, which in turn leads to increased water pollution, reduced access to fuel wood, eroded soils, increased vulnerability and ultimately to the degradation of these resources on which the poor depend. Although data on the impact of poverty on the environmental resource base in Central America is scarce, the high incidence of poverty is known to have a significant impact on the harvesting of fuel wood, as fuel wood is consumed mostly by the poor and marginalized who lack access to other energy sources

(CCAD, 1998; Kaimowitz and Paupitz, 1999). It is calculated that approximately 90% (26.3 million cubic meters) of wood is used as fuel wood either domestically or in industrial processes in the region, with much of this being harvested by the poor for subsistence (Proyecto Estado de la Región, 2003).

Land tenure, speculation and distribution

Other factors that have significantly contributed to the expansion of the agricultural frontier in Central America include problems of land access, unequal land distribution and insecure land tenure. Central America has serious problems of land access as well as an extremely unequal distribution of land. For example in Guatemala, 65% of the land in agriculture belongs to only 2.6% of the population; similarly, in Honduras, 55% of the land belongs to 4% of the population (ICCO, 1997). Despite serious attempts at agrarian reform and modernization, more than 1 million rural families in the region do not have access to land and these landless exert a large pressure on the remaining forested areas. With the last massive agrarian reform programs finishing in the 1990's, the problem of landless rural families is likely to remain a problem for years to come. At the same time, the rising prices of land throughout the region (with the exception of Nicaragua), due to the provision of improved access to previously unreachable areas and urban sprawl, will make land access even more difficult for the poor and further displace agricultural activities away from urban centers (Kaimowitz, 1996).

Another serious concern is the lack of secure land tenure. Even in areas where agrarian reforms were instituted, more than 70 % of all the beneficiaries of agrarian reforms in the region do not possess secure property rights, mostly due to badly planned reforms based on a massive but disorderly assignment of land that was not previously screened for quality, basic infrastructure or access (Coalición Internacional para el Acceso a la Tierra, 1998). The lack of secure property rights is also a problem for many of the region's indigenous communities, many of which overlap with the last remaining large forests (PROARCA, 1998). Despite the general (but debated) assumption that indigenous communities in general are able to manage properly the resources available, few communities have received property rights to their land (Kaimowitz, 1996). An interesting exception is

Panama that has given the property rights of approximately 700,000 ha to the indigenous communities of Kuna Yala and Embera (Kaimowitz, 1996).

Insecure land tenure in Central America has created strong incentives to small producers to extract as much resources as possible in the shortest time span, and then move to clear new patches of land (Feder and Feeny, 1991; Knox *et al.*, 1998; Pagiola 1999). These small producers make virtually no investment in the land because of the fear of losing it to other, stronger players (PROARCA, 1998). In addition, lacking secure property rights and assets to back loans, few have access to formal credit systems, which makes it difficult from them to invest in improving and maintaining their farmland.

Governmental policies and laws

Governmental policies and laws have also contributed significantly to the expansion of the agricultural frontier, the intensification of existing agricultural systems and changes in agricultural landscapes. Historically, the most important policies have been those directly relating to the colonization of new areas- particularly the way in which governments recognized rights to newly deforested land. In the past, Central American countries had laws that allowed settlers to claim property rights to governmental land if they could demonstrate that they had been actively using the land for a given period of time. One way of proving these ties was to clear the forest and establish agricultural practices. Consequently, many land speculators took advantage of these laws to acquire new land and then sell it after a few years at a profit (Cruz *et al.*, ___cited by Kaimowitz, 1996). Because bare land was considered more valuable than forested land (in total disregard of the value of timber), many land owners decided to clear their remaining forest cover in order to increase the value of their land, avoid illegal invasions onto their property or its inclusion in agrarian reform programs (Place, 1981; Edelman, 1992; cited by Kaimowitz, 1996). In recent years, however, these perverse incentives that encouraged land clearing in order to get tenure rights to the land have since been eliminated.

Another example of a government policy that led to widespread deforestation were inappropriate credit policies of the financial sector in the second half of the 20th century

that assigned no value to land under forest cover and required its conversion into agricultural land in order to be eligible to credit (Nygren, 1999; Stewart, 1992, Kishor and Constantino, 1993, Stewart and Gibson, 1994; cited by Kaimowitz, 1996). The maintenance of land under forest cover was further discouraged by forestry laws that assigned total control of timber, whether planted or natural, to the central government, which allowed extraction only after permits were requested and approved. Although these restrictions were intended to reduce deforestation, they actually had the opposite effect, stimulating producers to engage in illegal logging (Kaimowitz, 1996).

Other, more indirect, policies that have significantly impacted agriculture and biodiversity in the region include the use of subsidies to promote the expansion and intensification of agricultural and livestock production, at the expense of forests (OECD, 2003). Probably the most important perverse incentive in the Central American context has been the availability of highly subsidized credit for livestock production, targeted mostly to a reduced number of ranchers dedicated to extensive beef production². Livestock farmers were not only eligible for subsidized credit from Central American governments, but also received protection from land expropriation, higher prices, and tariff protection for meat and dairy products (Kaimowitz, 1996). This subsidized credit contributed to deforestation, not only by providing incentives for cattle farmers to convert more land into pastures and increase livestock production, but also by encouraging other landowners to clear their forest cover in order to qualify as livestock producers and access the subsidized credit for other purposes (Kaimowitz, 1996; Wendland and Bawa, 1996).

Central American governments have also often promoted large-scale projects which have encouraged agriculture (at the expense of forests) and had serious environmental consequences. A good example was the construction of the Arenal Tempisque Irrigation District (DRAT by its Spanish acronym) by the Costa Rican government, financed with a loan from the Inter American Development Bank, which was intended to promote irrigated agriculture in the region. Studies have shown that the highly subsidized access to irrigation for rice production has led to extreme water use inefficiency in the district, as well as

² In the 1980's even international aid agencies (BID, WB, USAID) dedicated much of their funds to provide incentives for the expansion of livestock production (Kaimowitz 1996).

severe environmental degradation due high pesticide associated with this crop (Madrigal, 2003; Tribunal Ambiental Administrativo, 2001). Excessive runoff from these rice fields is also having a great negative impact on the Palo Verde National Park (a RAMSAR site) and on the fishing industry in the Gulf of Nicoya (Chakravorty and Chen, 2001; Mateo 2001,).

On the other hand, some governmental policies and laws are clearly aimed at preventing agricultural expansion, reducing dependence on pesticide use, and promoting more sustainable agriculture and are having a beneficial impact on biodiversity. Some examples include the creation of an extensive system of protected areas in the region (covering an estimated 25% of the land in Central America, Proyecto Estado de la Región, 2003), the adoption of laws that permit payments of environmental services to farmers, the adoption of forestry laws that promote sustainable forest certification management, and the promotion of the Mesoamerican Biological Corridor (CCAD 1997; Chomitz *et al.*, 1998; Miller *et al.*, 2001)

International prices and consumption tendencies

Because of the region's high dependence on export crops, the high volatility of international markets for agricultural products (both in terms of changing prices and access to particular markets) has a great effect on the pattern of agricultural production in Central America and overall land use (Proyecto Estado de la Región, 2003). As mentioned earlier, the historical expansion and contraction of areas dedicated to the production of cotton, coffee and livestock, for example, are directly related to fluctuations in international market conditions, and changes in the prices of these commodities can have enormous impacts on the region's agriculture. This situation is greatly aggravated by the dependency of the Central American economies on imports of fossil fuels and the need to increase agricultural exports as means to raise the foreign currency necessary for paying rising international oil prices (Hall *et al.*, 2000).

Expansion of roads and infrastructure

The construction of roads and infrastructure (houses, schools, clinics, processing plants, etc.) in previously inaccessible and remote areas has also greatly contributed to the

expansion of agriculture into new areas, and the intensification of agriculture towards market-orientated crops, as this infrastructure makes regions more accessible and more attractive to rural people. Roads, in particular, have a powerful effect on the pattern of land use and on the expansion of the agricultural frontier, and on land speculation, as they allow landless farmers from other regions to homestead new farms on unclaimed forest land and stimulate the expansion of the agricultural frontier (Chomitz and Gray, 1996; Geist and Lambin, 2001, 2002).

Throughout Central America, the establishment of new roads has accelerated migration to frontier regions and facilitated increased deforestation (Sader and Joyce, 1988; Sunderlin and Rodríguez, 1996; Rosero-Bixby and Palloni, 1998; Southworth and Tucker, 2001). A clear example of this link between road construction and agricultural expansion comes from the Sarapiquí area of Costa Rica, where the establishment of a highway in the 1960's and 1970's that connected the Atlantic region with San José rapidly resulted in increased migration and deforestation in the region, changing the previously forested Atlantic slope to a mosaic of banana plantations and pastures (Sader and Joyce, 1988; Montagnini, 1994). This pattern was repeated throughout the country: between 1967 and 1977, Costa Rica's network of roads doubled from 2,088 km to 5,582 km, and at the same time deforestation rates soared (Sader and Joyce, 1988). Similarly, in northern Honduras, the construction of new roads in the upland communities of the River Cuero watershed that connect to the coastal plain and the main road have resulted in a flux of in-migration and contributed to forest clearing in the buffer and core zones of the Pico Bonito National Park (Humphries, 1998). Finally, it is thought that El Salvador lost its forest many decades earlier than other Central American countries in part because it took the lead in road and bridge building and this facilitated migrant access to forest areas (Utting, 1996).

The rapid expansion of roads in the region stems both from specific colonization and development projects, as well as from logging and other industries. In some cases, the construction of public roads has been associated with specific colonization projects, such as the case of Nueva Guinea, Nicaragua, the northern part of Guatemala and the Valle Aguan project in Honduras, to name a few. In others, large road projects like Chiriquí-Bocas del Toro and Tiraó-Canglon in Panama, Las Cruces-Naranjo in Petén, Guatemala, San José-

Guápiles and the Rió Blanco-Siuna-Nueva Guinea-Bluefields project in Nicaragua attracted agricultural pioneers and central governments were unable to prevent the development in areas adjacent the new infrastructure (Kaimowitz, 1996). A final driving force in the expansion of roads and infrastructure has been the expansion of industries based on the extraction of natural resources (timber, oil, gas, water). These industries build roads for short-term extraction projects, which are subsequently abandoned and used by pioneers for access to previously unexploited areas (Utting, 1993). For example, the colonization of western Panama in the early 1980's was in part due to the opening of new roads for mining and pipeline maintenance (Utting, 1996). Road infrastructure is likely to continue to increase in recent years, particularly in countries that currently have low road densities (Table 11). In the future, particular attention needs to be paid to the construction of the Pan-American road through Darien, Panama and the expansion of infrastructure in Petén, Guatemala, which pose a significant threat to the conservation of biodiversity in those particular areas. In the case of Darien, an added risk is the invasion of diseases (like foot and mouth disease) from South America to Central America and vice versa (Bryant *et al.*, 1997).

Table 11. Length and density of roads per country in Central America. The total length and density of roads include both paved and unpaved roads.

	Year	Total length in km	% of length paved	density (km/ha)
Belize	1998	2,872	17.0	1.3
Costa Rica	2000	35,892	21.0	7.0
El Salvador	1997	10,029	19.8	4.8
Guatemala	1998	13,856	-	1.3
Honduras	1996	15,400	20.3	1.4
Nicaragua	1996	18,000	10.1	1.5
Panama	2001	11,717	35.5	1.6

Source: ECLAC (2002)

Market failures

The lack of a complete set of properly functioning markets which recognize the value of forests and their biodiversity is also an underlying cause for the expansion of the

agricultural frontier. There are two main reasons why markets fail to capture the value of biodiversity. First, because there is not enough information about the value of biodiversity, non-intervened markets (and farmers) generally treat it as a low value commodity. Second, because the benefits of forests and biodiversity conservation serve the public good (rather than the individual who conserves them), it is difficult to promote their conservation unless a regulatory agency exists to ensure that society pays for these services, effectively tipping the balance of the farmers decision making process in favor of biodiversity and against short term extractive gains.

Examples of market failures which directly influence agriculture in the region include the misguided lending practices of the Central American financial sector which has generally regarded biodiversity and forest as valueless and required clearing the land from its natural cover in order to get access to credit and has often linked crop insurance to the adoption of technological packages with intensive agrochemical use which negatively impact the environment (PROARCA, 1998).

Technological Factors

The promotion of new agricultural technologies (i.e. new seed or animal varieties, new management practices, or intensified use of pesticides and fertilizers) also plays an important role in determining agricultural patterns, though it is not clear what their net impact is on deforestation. In general, farmers tend to first increase production by extending production to new land adjacent to already established plots, and only look to intensification or the adoption of new technologies when it is no longer possible to expand further (Schneider, 1995; Angelsen and Kaimowitz, 2001). For example, livestock production at the Atlantic side of Costa Rica has increased on the basis of expansion into new areas; in contrast the in the Pacific side of the country where land is scarce and prices are increasing, cattle ranchers are increasingly looking to improved technologies to maintain farm productivity, and are rapidly adopting the use of improved grasses, supplements and other technologies (White *et al.*, 2001).

There is some controversy regarding the impact of technological improvements on deforestation (Carpentier *et al.*, 2000; White *et al.*, 2001; Angelson and Kaimowitz, 2001). On the one hand, introducing improved technologies holds the potential to prevent the cycle of land degradation and deforestation by making farming systems productive for longer periods of time. On the other hand, if these new varieties of pastures and improved management practices increase the profitability of cattle ranching, they could further encourage ranchers to expand into new areas. These conflicting outcomes serve as a reminder that there is no simple, straightforward solution to the problem of expansion of agriculture into the few remaining natural areas in the region.

A related factor which may be contributing to inefficient intensification practices is the lack of adequate transfer of technological developments. Although several NGO's and research institutions are making significant efforts to develop innovative production methods that can enhance production while minimizing environmental impact, this information is not reaching the final producers who require it in order to use their land more profitably and sustainably. Most organizations dedicated to sustainable agriculture do not have the necessary funds to carry on with large scale capacity building efforts outside the area covered by their research projects and governmental extension programs are similarly often under funded and plagued by bureaucracy (PROARCA, 1998).

Biophysical factors

In many areas of Central America, agriculture is constrained by steep slopes, that are highly vulnerable to soil erosion and nutrient loss, and poor quality soils (De Groot and Ruben, 1997). Agricultural production in these areas is usually low and farmers are generally forced to abandon plots after two to five years of use, due to declining productivity. Although the use of fallows had helped alleviate this problem, increasing population pressures have reduced (and in some cases even eliminated) fallow periods, making these systems unsustainable (CCAD, 1998).

CAFTA

A final factor that is likely to have a dramatic (but still largely unknown) impact on agricultural activities in Central America is the adoption of the Central American Free Trade Agreement (CAFTA, or TLC in Spanish). This agreement, which was signed by Guatemala, Honduras, El Salvador, Nicaragua and Costa Rica, and the United States of America in January 2004 and is now pending ratification by the respective congresses and parliaments, is a key element of USA's policy towards Central America and will have strong impacts on the region, affecting not only trade, but also the overall socioeconomic development of the region.

There are two main ways in which CAFTA is likely to affect agricultural activities in the region. First, CAFTA introduces new laws that forces exporters to comply with local environmental regulations; if exporters fail to meet environmental standards, the host country may be fined. This provision is expected to improve environmental conditions (and compliance with forestry and natural resource management laws) in the short run, but may hurt the development of new, more advanced, environmental regulations as countries become wary of having strict environmental laws that they cannot abide by. Second, trade liberalization is expected to increase the flow of some agricultural products from Central American countries to the USA and create new markets for a subset of products; however other products will likely see their markets destroyed by CAFTA. Consequently, it is expected that agriculture in Central America will change towards those crops favored by the free trade agreements, with countries specializing on certain agricultural products. Which crops will be favored is not yet clear, and may vary across individual countries based on the specific terms of their negotiation within CAFTA. While it is not possible to predict the precise impact of CAFTA, it is clear that, if ratified, it is likely to dramatically change the patterns of agriculture in the region, and potentially, drive the expansion of agriculture into new land to meet the requirements of large scale production technology and increased fragmentation of already scarce natural patches of vegetation. A more detailed discussion of the possible effects of CAFTA on Central American agriculture is presented in Appendix 7.

Linkages between agriculture and biodiversity loss

Having discussed in detail the main trends in agriculture and the factors affecting these trends, we now consider the different ways in which agriculture can affect biodiversity, and the factors that influence these impacts. The most immediate impact of agriculture is the conversion, destruction or modification of natural habitats, which reduces the habitats and resources available for plant and animal life and leads to huge, and often irreversible changes to the environment. However, agriculture also affect biodiversity in many more subtle and indirect ways (Figure 3). The mechanisms by which agriculture affects biodiversity are nonlinear, non-independent, and complex, and can occur on different temporal and spatial scales and with different intensities. To complicate matters further, the effects of agriculture may occur both on-site and off site, with some impacts occurring directly at the site of the agricultural system and others (such as siltation or pollution of streams or rivers) having impacts many kilometers away. The magnitude of these effects may also vary from one site to the next, depending on the particular biophysical, ecological and socioeconomic context of a given site. Thus, understanding the nuances of how agriculture affects biodiversity is necessarily complex.

In an attempt to better visualize (and simplify) these interactions, our conceptual framework divides the effects of agriculture into direct and indirect effects, as well as effects that occur on-farm versus off-farm (Figure 3). The direct, on-farm effects include the deforestation and conversion of natural habitats to agricultural land, the fragmentation of the remaining natural habitats and concurrent loss of landscape connectivity, the degradation of the remaining habitat through hunting, plant or animal extraction, and entry by domestic animals, and the introduction (and potential spread) of non-native species, including genetically modified organisms. Other direct effects which occur off-farm include the pollution of rivers, streams, and near-shore marine ecosystems with fertilizers, pesticides and sediments. In addition to these direct effects, agriculture may also impact biodiversity indirectly through changes in ecological processes (e.g. water cycles, fires, nutrient cycling or pest dynamics), the invasion of exotic species, and changes in infrastructure that usually accompany agriculture and may further reduce natural habitat availability. Our model does not include feedbacks, or synergisms although it is likely that

such interactions do exist. Similarly, we do not attempt to assess the relative impact of each factor on biodiversity conservation, as this will be particular to the specific context of each place.

On-farm direct effects

Deforestation

As in other tropical regions, the widespread conversion of forests to agricultural land poses the key threat to biodiversity conservation in the Central America region. Deforestation leads to the loss of native plant communities, the loss of habitat and resources for wildlife, and the disruption of ecological processes such as seed dispersal, pollination, and animal dispersal. As a consequence, deforestation is usually accompanied by a loss of biodiversity at the genetic, species and ecosystem level. Species that are particularly vulnerable to deforestation include species that require large contiguous forest areas, ‘forest-interior’ species that can only survive in intact forests, endemic species with a small geographical range, or species with small population sizes that are vulnerable to extinction (Laurance *et al.*, 1998). For example, in Central America, species that have been identified as particularly vulnerable to population declines or local extinctions due to deforestation include large mammals (such as jaguars, tapirs), forest-interior species and endemic species that occur in areas which have been highly impacted by deforestation, or species that are heavily hunted by farmers (e.g. peccaries, agoutis, and large birds).

Although the extent of deforestation in Central America is well documented and the impacts on biodiversity obvious, surprisingly little scientific data exists on the impact of this deforestation on biological communities in the region, due to the lack of long-term studies comparing forested areas prior and after deforestation, or even comparisons of forested landscapes to adjacent landscapes which have been highly impacted by agriculture (though the vegetation remaining in agricultural landscapes has been well characterized; e.g. Kappelle *et al.*, 1993, 1998, Harvey and Haber 2000). Most studies documenting the effects of deforestation point to the absence of large mammal species in highly deforested areas or to their reduced population size (e.g. the reduction of jaguar and peccary populations in the Corcovado National Park (Carrillo *et al.*, 2000), or the disappearance of

spider monkeys and tapirs from montane forests in Central America, Brown and Kappelle, 2001), as evidence of the effects of deforestation, or make crude estimations of the numbers of species threatened by agriculture. For example, Brooks and colleagues (2002) estimate that as many as 1,656 endemic plant species and 384 endemic vertebrate species have been lost from Mesoamerica due to deforestation and that a similar number of species will be lost by 2007, if deforestation rates continue to be high as expected (Table 12). The continuing deforestation and advance of the agricultural frontier will likely continue to impact biodiversity, by reducing habitat and resources available, as well as landscape connectivity, but the main impact of deforestation has probably already occurred

Table 12. Predicted number of extinctions of endemic plant and animal species in Mesoamerica, based on deforestation rates.

Hotspot	Deforestation rate (FAO 1997)*	Area (% km ²)		Plants			Vertebrates		
		Now	5 years	Total	Predicted extinctions	Future extinction	Total	Predicted extinctions	Future extinctions
Mesoamerica	2.13	0.2	0.179	20,000	1,656.3	1749.1	1159	383.9	405.4

Source: Brooks *et al.* (2002). *Average for México, Belize, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica y Panama.

Forest fragmentation and changes in landscape structure and composition

Deforestation of areas for agricultural production often results not only in the loss of forest habitat, but also in the fragmentation of large areas of forests into numerous, small blocks that are often physically isolated from one another. Forest fragmentation is generally thought to have three main effects- the reduction of large habitat blocks into smaller areas, the creation of edges between forest and non-forest habitat which experience diverse physical and biotic changes associated with the abrupt margins of the forest fragment, and the isolation of fragments from intact forest- all of which, in turn, can affect the habitat quality of forest fragments and their ability to maintain biodiversity (Saunders *et al.*, 1991; Barbault and Sastapadja, 1995; McNeely *et al.*, 1995; Bennett, 1999; Bierregaard *et al.*, 2001; Kattan, 2002). Populations in small forest fragmented are likely to be small and consequently more vulnerable to random effects such as genetic drift, inbreeding and stochastic demographic changes (Gilpen and Soulé, 1986). In addition, small forest fragments will only contain a subset of the species occurring in the continuous forests and will therefore provide only a subset of the habitats and food resources originally present;

they may also experience only a subset of the ecological interactions (Bierregaard *et al.*, 2001). Finally, edge effects (which may extend up to 300 m from the forest edge) may range from changes in soil moisture and air temperatures, to changes in bird densities, tree recruitment, tree mortality and the invasion of disturbance-adapted species (Laurance, 1997, Oosterhoon and Kappelle, 2000, Forero and Finegan, 2002). Consequently, the net impact of converting forests to agricultural production extends far beyond the area directly deforested.

Although data from Central America are scarce, data from the long-term study of fragmentation in the Brazilian Amazon suggest that certain animal groups are more vulnerable to fragmentation than others. These include understory birds, primates, shade-loving butterflies, solitary wasp, carpenter and leaf-cutting bees, euglossine bees, coprophagous beetles, forest interior beetles, termites, ants, flying insects, drosophilid fruit flies, forest interior seedlings, palms, and existing canopy and supercanopy rainforest trees (Bierregaard *et al.*, 2001 and references therein), as well as large mammals such as jaguars and tapirs. In addition, these studies suggest that many forest species are unable to cross even narrow clearings within forests, and are effectively isolated when forest patches are surrounded by cattle pastures, crops or other non-forest habitats. Other species, in contrast, appear to tolerate open conditions or second growth habitats more easily.

Despite the high level of forest fragmentation in Central America, there are only a handful detailed studies that have documented these patterns, although spatial analyses are likely to become more common as GIS capabilities in the region increase. These studies clearly illustrate that fragmentation has severely affected vast areas of Central America and is a major threat to biodiversity conservation. For example, a study by Sanchez-Azofeifa and colleagues (2001) showed that the loss of 2250 km² of forest in Costa Rica from 1986 to 1991 was accompanied by a sharp increase in the number of forest fragments, particularly small fragments (with 524 new forest fragments of 0.03- 0.5 km² in size being created during this period). The degree of deforestation and fragmentation was particularly severe in the Tropical Moist Forest and Premontane Moist Forest, where little forest cover remains and the mean forest patch size is small (Table 13). Studies at smaller scales show similar trends towards more fragmented landscapes and smaller forest fragments. For example, Maldonado (1997a, b) show that the previously-forested areas between the Parque Nacional

Corcovado and the Parque Nacional Piedras Blancas which was previously a continuous area of forest, has been largely converted to secondary forests, crops and pastures (which together account for 46% of the area) and only small forests (typically less than 20 ha) remain in the landscape outside of the park. A similar study by Sanchez Azofeifa *et al.* (2002) in the Osa Peninsula similarly showed that mean forest fragment size had declined from 2.2 km² to 0.7, from 1979 to 1997, while the number of forest fragments increased from 445 to 1241 in the same period. Finally, a number of landscape-level studies in Costa Rica and Nicaragua illustrate the widespread deforestation, high fragmentation level, and dominance of agricultural land use in specific sites (Kramer, 1997; Correa do Carmo *et al.* 2001; Chacón, 2003; Salazar, 2003).

Table 13. The extent and fragmentation of remaining forest cover in Holdridge life zones of Costa Rica in 1991.

Life zone	% forest cover	Number of forest islands	Mean patch size (km ²)
Tropical Moist Forest	5	961	0.5
Tropical Wet Forest	39	2572	1.6
Premontane Moist forest	2	265	0.3
Premontane Wet Forest	19	3873	0.5
Premontane Rain Forest	60	742	2.8
Moist Forest Lower Montane	16	129	0.3
Lower Montane Wet Forest	45	495	1.0
Lower Montane Rain Forest	84	271	10.7
Montane Wet Forest	37	12	0.5
Montane Rain Forest	90	38	30.2

Source: Azofeifa-Sanchez *et al.* (2001)

Hunting

Many subsistence farmers living near protected areas or on the agricultural frontier complement their agricultural production by hunting for wildlife, either for family consumption, or less commonly, for sale. Consequently, as new areas of forests are opened to agriculture, the hunting pressure on wildlife is usually exacerbated; hunting is also a primary threat to the conservation of wildlife in forest patches that are retained within

agricultural landscapes. Large mammals (such as tapirs, monkeys, peccaries, and agoutis) and birds are particularly affected by hunting, and many have suffered decreases in their populations due to heavy hunting pressure (Redford, 1992; Carrillo and Vaughan, 1994). Some hunting is authorized by local governments, though in most cases these regulations are rarely enforced and not enough information is available about the biology of the hunted species to know whether or not the regulations (even if properly applied) are adequate to protect a given species (Carrillo and Vaughan, 1994).

While detailed studies are scarce, studies conducted in the Corcovado National Park, the Reserva Forestal Golfo Dulce and buffer zones which are inhabited, found that animal species that were heavily hunted were less abundant in the buffer zones than in the park, suggesting a strong impact of hunting on these populations (Carrillo *et al.*, 2000). Similarly, in the Talamancan mountain range, tapirs and overall mammal abundance were low in areas with greater human presence, reflecting high hunting pressure (Guiracocha *et al.*, 2001; Tobler, 2002). Often, it is a combination of habitat loss, habitat degradation and hunting which leads to the local loss of species, rather than hunting alone.

Extraction of firewood, timber and other products

Another indirect impact of agriculture is the accompanying demand and pressure on remaining forests for firewood, timber and other products by the farmers who live adjacent to the forest boundaries or who retain forest patches within their farms. Despite the fact that all Central American countries have a legislature banning the harvesting of timber and other products from national parks, in practice these regulations are rarely enforced. Consequently, as human presence increases in areas that were previously extensive forests and forest resources become scarce, the pressure for forest products (both timber and non-timber) increases. With the exception of Costa Rica, farmers in most Central American countries still rely heavily on firewood for cooking and there is therefore a high demand for firewood. For example, in Guatemala, it is estimated that roughly 40% of the timber harvested is used for firewood, with each person annually using one ton of firewood (Islebe and Veliz Perez, 2001). Extraction for firewood has been cited as a major threat to at least 8 of the ecoregions in Central America (Dinerstein *et al.*, 1995; Figure 1), including cloud forests in Guatemala (Islebe and Veliz Perez, 2001) and Nicaragua (Walsh, 2001).

Introduction of alien and invasive species

Another way in which agriculture may indirectly affect local biodiversity is through the introduction of non-native species which may negatively affect existing native species (through competition, predation, parasitism or disease) or invade adjacent remnant forests. For example, cows, horses and other domestic animals are known to compact soils, trample regenerating plants and damage understory plant communities in forest fragments and riparian areas, potentially affecting the long-term vegetation dynamics of these forests; consequently the fencing of forest fragments to restrict cow entry is key to conservation efforts (Guindon, 1996). Similarly, domesticated cats and dogs often hunt local wildlife, adding stress to communities already impacted by deforestation and fragmentation, although there are no data on the potential magnitude of this impact.

In other regions of the world, agriculture has commonly resulted in the introduction of invasive species, at the expense of native species, however there is little information in Central America to assess the degree to which this is a problem (Hernandez *et al.*, 2002). The Invasive Species Specialist Group of the IUCN has identified a list of invasive species present in each of the Central American countries (Appendix 8), but this list is woefully incomplete. Not surprisingly, many of the species that appear on this list are species associated with agriculture- such as the feral pigs that were introduced to Cocos Island (Costa Rica) by settlers, the Mediterranean fruit fly that has colonized fruit plantations throughout the region, the guava tree (*Psidium guajava*) that is cultivated for its fruits, and the thatching grass ('Jaragua', *Hyparrhenia rufa*) that was established in pastures in Pacific lowlands of Costa Rica and Nicaragua by cattle farmers (Hernandez *et al.*, 2002). Alien grasses could pose a particular threat to forest ecosystems in the region, because they already cover vast areas of land, actively prevent the regeneration of trees on deforested areas, increase the possibilities of fires which can spread into the remaining forested areas, and are often difficult to eradicate. In Panama, for example, efforts to control paja blanca (*Saccharum spontaneum*), a grass that was established by farmers in the 1950s and 1960's, have largely failed due to the aggressive nature of this grass (Palencia, 2000). Similarly, efforts to rid pastures of the Retana grass (*Ischaerum ciliare*) in Sarapiquí, Costa Rica, have failed because its prolific seed production and dispersal permits the rapid recolonization of cleared areas (Muñoz, 2004).

A related problem is that agriculture has turned some native species (such as grackles, jays, rodents and others) into pests, by dramatically increasing the availability of food for these species while also eliminating competitors and predators.

Introduction of genetically modified organisms (GMOs)

A special case of interest to biodiversity conservation efforts is the introduction of genetically modified crops or GMO's (i.e. crops that have received genes from other organisms to confer certain characteristics or traits such as herbicide tolerance or insect resistance). To date, the only Central American country which has openly cultivated genetically modified organisms is Honduras, which has a total of 2,000 ha of genetically modified maize (Cevallos, 2004). Costa Rica produces seeds of transgenic maize for export, but does not plant this maize locally. However, it is possible that the area covered by GMO's will increase in upcoming years.

The potential environmental impacts of GMO's are still unclear and widely debated (Conner *et al.*, 2003). Advocates argue that the use of GMO's that are herbicide tolerant or insect resistant can result in the reduction of herbicide use and production costs; however opponents argue that there is a threat that GMO organisms will spread into natural systems, potentially interbreeding with natural relatives and thereby decreasing biodiversity, or that these plants will become 'superweeds' that are difficult to control (Conner *et al.*, 2003, McNeely and Scherr, 2003). There is also controversial evidence that Bt-maize (a modified strain that produces the biological pesticide *Bacillus thuringiensis*, Bt) can have adverse effects on monarch butterflies, in addition to the pest insects it was designed to counteract (Hansen Jesse and Obryeki, 2000, Hellmich *et al.*, 2001). Since transgenic varieties are relatively new and adoption in Central America is still low, the long-term impacts of this technology are still unknown.

Off-site direct effects

Pollution of rivers, streams and coral reefs with agrochemicals

Perhaps the most important off-site effect of agriculture is the contamination of natural ecosystems with agrochemicals (pesticides, fertilizers and other chemical inputs). The heavy use of agrochemicals (particularly in agricultural commodities produced for export, see Table 14) can severely pollute soil and water resources, as chemical residues drift into surrounding air, water and soil, affecting both terrestrial and aquatic ecosystems. Since pesticides often enter waterways via runoff, they may be carried to other areas and affect water quality in both freshwater and coastal ecosystems further away (Castillo and Clements, 1993; Castillo *et al.* 2000). The effects of these chemicals range from the direct death of animals that ingest pesticides, to the possibility of the contamination of offspring through the passing of chemical residuals through the placenta in mammals, or through eggs in birds and reptiles (Brown, 2003). The threat of pesticides is particularly of concern for larger animals that feed higher in the food chain and are likely to accumulate higher concentrations of these compounds, because they accumulate the organochlorine compounds concentrated in their prey and since they live longer, they have a greater time to accumulate the compounds (Klemens *et al.*, 2003).

Table 14. Estimation of pesticide use in crops present in the irrigation zone of Arenal-Tempisque, Costa Rica (in kg of active ingredients per ha per year).

Crop	Herbicide	Insecticides	Fungicides	Total	Most commonly used pesticides*
Rice	5-10	0-1	0-2	5-15	Propanil, Quinclorac, Metamidophos
Sugarcane	1-5	0-1		1-6	Diuron, 2,4-D, Ametryne, Parathion-methyl
Pasture	0-0.5	-	-	0-0.5	
Vegetables and fruits (melon, watermelon)	0-1	5-15	5-20	10-30	Mancozeb, Benomyl, Carbofuran, Methomyl, Chlorothalonil, Deltamethrin, Captan

Source: Castillo and Ruepert, 1993.

* English names taken from <http://www.pesticideinfo.org/Index.html>

Although the information on the effects of pesticides on biodiversity are incomplete, the few studies that have examined the presence of pesticides and other chemicals in soils, water and agricultural products, indicate that pesticide contamination is a serious problem throughout the region. For example, Klemens *et al.* (2003) who sampled tissues amphibians, turtles birds and mice from the Guanacaste National Park in northwestern Costa Rica for organochlorine pesticide contamination, found that 6 of 39 amphibians, three of six turtles (2 species), one of eight mice (one species) and 19 of 55 birds (five of seven species) contained high levels of organochlorine pesticide, indicating that pesticide use in surrounding agricultural landscape is impacting the biodiversity within the park, most likely through atmospheric transportation from the agricultural areas to the east of the conservation area (Klemens *et al.*, 2003). Most of the organochlorine contaminants in this area were metabolites of DDT, a chemical whose use was restricted to antimalarial uses in the 1980s' and banned in 1990, but still appears to be used illegally (Klemens *et al.*, 2003). Another study in the Tortuguero Conservation Area in northwestern Costa Rica, found that pesticides from the banana producing regions near the park were present in high concentrations in the aquatic systems within the park and presented danger to the aquatic ecosystems within the reserve (Castillo *et al.*, 2000). Similarly, in other banana-growing regions of Costa Rica near the Cahuita National Park, heavy metals were detected in the waters surrounding coral reefs, in superficial water, sediments, subterranean water and aquatic organisms (Abarca, 1992). Studies along the south coast of Guatemala (where bananas are grown) have reported residues of 38 types of chemicals, including organochlorines, organophosphates and pyrethroids in the drinking water of the region (DANIDA 1998). There have also been reports from Costa Rica of pesticides causing the death of bees, fish (both wild and domesticated) and wild birds, but few details are available (García, 1997). Finally, in the Cholutecan River Basin of Honduras (where cotton, basic grains and vegetables are grown), studies have shown residues of pesticides in soil, water and fish tissues, with a total of 20 types of organochlorines and 9 organophosphates being detected (Kammerbauer y Moncada ,1998).

The threat of pesticides to plant and animal communities is a function of the number and frequency of pesticide application, the toxicity of the pesticide and persistence in the

environment, the proximity of application to aquatic ecosystems, the application technique (aerial or manual, localized or widespread), as well as the particular climatic conditions at the time of application (de la Cruz and Castillo, 2000). In addition, the effects of pesticides on current plant and animal communities depends not only on current pesticide applications, but also on past land use. In many regions where organochlorine compounds were widely used in the 1970's (before being banned in most countries in the 1980's), pesticide residues still occur within soils and water. For example, a study of the pesticides present in the Cholutecan river basin of Honduras, found that many organochlorine pesticides that were present were residues of earlier pesticide applications to cotton production systems that were used in the 1970's (Kammerbauer and Moncada, 1998). Consequently, the effects of pesticide use may have long-lasting effect on natural ecosystems.

Finally, it is important to note that heavy pesticide use is not only causing environmental problems but also creating agricultural problems, as some pest species become resistant to pesticide use, rendering conventional pest control methods obscure. According to the FAO, a total of 504 arthropod species, 150 phytopathogens, 125 weed species, 5 rodent species and 2 nematodes had shown signs of resistance worldwide (García, 1997). Notable cases of insect resistance in Central America include *Besmisia tabaci* in tomato and tobacco fields, and *Athonomus grandis* in cotton fields, both probably resulting from excessive and inadequate pesticide use (García, 1997).

Soil erosion

The widespread conversion of forests to agriculture has created serious soil erosion problems in the region with an estimated 75% of Central America's agricultural land being classified as degraded (McNeely and Scherr, 2003). Almost all of the countries in Central America have been affected by soil erosion, however erosion is particularly problematic in Panama, El Salvador and Guatemala which rank among the world's most eroded countries (Utting, 1996). A report by FAO indicated that 90% of Panama's total land area was affected by erosion in the mid 1980's, of which 16% was seriously affected. Similarly,

erosion is estimated to affect 77% of El Salvador's national territory and an estimated one third of Guatemala's land surface (Utting, 1996).

By removing forest cover, agriculture exposes soils to the erosive effects of wind and water and increases topsoil loss to erosion. In general, annual cropping systems are most prone to soil erosion because frequent cultivation, weed control and harvesting leave the bare soil exposed at different times of the year, however perennial crops can also suffer high soil erosion, particularly if herbicides are used to maintain a clean understory, or if these systems are established on steep slopes (McNeely and Scherr, 2003; Clay, 2004). For example, soil erosion is often high in banana and pineapple plantations where all understory vegetation is frequently removed with herbicides, or in sugarcane fields in the months following harvesting when the soil is left unprotected. Soil erosion can also be considerable on degraded pastures, (particularly if grass cover is patchy) and cattle movement in pastures can lead to increased soil compaction, which leads to increased water runoff as the number of large and medium soil pores is reduced (Pimentel *et al.*, 1995; Utting, 1996). Soil susceptibility to erosion will depend not only on the type of production system and the particular management and strategies employed, but also on soil type, topography and climatic conditions. In general, the fertile volcanic soils on the Pacific coastal zones and hilly interiors are highly susceptible to erosion when forest cover is removed, while the less fertile soils in the Caribbean plains are more prone to leaching. Soil erosion is particularly acute along the Pacific coast of Central America, where high population densities, the growth of commercial agriculture and the increased demand for fuel wood have led to widespread deforestation and soil erosion (Utting, 1996).

The effects of soil erosion on biodiversity are not well studied, but it is thought that it may lead to the loss of micro and macro organism diversity in soils (Pimentel *et al.*, 1995; 1999), as well as leading to the siltation of streams, rivers and coral reefs which can negatively affect these communities. Erosion also has important implications on farm productivity, as erosion removes the most productive topsoil which is important for soil fertility and crop yields. Soil erosion and degradation can affect soil depth, organic matter content, water holding capacity, physical structure, and chemical characteristics such as acidity and salinity (McNeely and Scherr, 2003). Over time, severely eroded soils are no longer profitable for agriculture and farmers will need to establish new areas for cultivation,

further expanding the agricultural frontier. Some of the abandoned areas may eventually return to natural vegetation, but many will be invaded by weedy species that outcompete native species.

Indirect effects of agriculture on biodiversity

Changes in intensity and frequency of fires

The use of fire in agriculture may also pose a threat to conservation efforts in Central America. Throughout the regions, fire is typically used for clearing vegetation and preparing a site for planting of crops or the establishment of pastures, or to stimulate grass regrowth. From an agricultural perspective, burning can have multiple beneficial effects, including clearing of unwanted vegetation and weeds from the field, eliminating insects and plant diseases from crops, increasing available soil nutrients, decreasing soil acidity, enhancing soil fertility with nutrient-rich ashes and reducing the labor and cost required to clear unwanted vegetation (Pasos *et al.*, 1994; Thrupp *et al.*, 1997). However, burning of agricultural lands often has a negative impact on biodiversity because it eliminates remnants of natural habitats and vegetation that may still occur within the agricultural landscape (thereby destroying habitats and resources for wildlife) and because fires may spread into remaining forest habitats and protected areas, destroying additional plant communities. Wildfires often spread beyond the agricultural areas in which they originate and may affect forests in adjacent protected areas: in recent years, large fires have been reported in the Parque Nacional La Lunga del Tigre and Las Montanas Mayas in Guatemala, as well as in Cruz del Río Grande in Wawashan in Nicaragua (Laforge, 2001). The prevalence of highly flammable pastures in many regions means that fires ignite and spread more rapidly, easily penetrating into forest edges (Kaimowitz *et al.*, 1996). The contamination of the air with smoke may also negatively affect animal populations. Although natural fires are known to occur in the tropical dry forests of Central America, it is generally agreed that fire is not a natural component of tropical moist forests and that plant communities in these areas are therefore not adapted to fire processes and do not easily regenerate after burning (Uhl *et al.*, 1988; Uhl and Kauffman, 1990). Repeated burnings may therefore quickly reduce species diversity in the affected area. In addition, once an area has burned, it is more likely to ignite again in the future (SCBC, 2001), creating a feedback loop that is hard to break.

While specific data on the number, origin and impact of fires initiated by agriculture are scarce, a significant proportion of the fires affecting the region are thought to be initiated by agriculture. A review by Billings and Schmidtke (2002), for example, indicates that the main source of wildfires in Central American is agriculture, though some wildfires are also initiated by lightning, by hunters flushing out wildlife from forests, or by carelessness (e.g. discarded cigarettes, etc; Table 15). Most of the fires within the region occur during the dry season (February to May) which coincides with the time when farmers deforest new areas for shifting cultivation, prepare land for crops that will be planted as soon as the first rains begin, burn existing pastures to stimulate grass regrowth or burn sugarcane fields to rid them of rats and snakes prior to harvesting (Middleton *et al.*, 1997; SCBD, 2001; Billings y Schmidtke, 2002). The areas that are most affected by wildfires tend to be areas with low human populations, little infrastructure and little state presence, dominated by cattle production, or in areas where illegal logging or shifting cultivation occurs (Laforge, 2001).

The area impacted by anthropogenic fires is considerable. One study estimated that in 1998 a total of 42,286 wildfires occurred in Central America, burning 1.1 million ha of land, of which 4449.9 ha were forest areas and 653.3 ha were agricultural lands or pastures (FRA, 2001). Another study indicated that more than 1.5 million hectares of forests in Central America and Mexico burned in 1999, including many protected areas (SCBD, 2001). Yet another study indicated that during the dry season of 1997-1998, over 13,000 forests burned in Nicaragua destroying vegetation on over 8,000 km of land (Matthews *et al.*, 2000). Fires originated by agriculture have also been indicated as important threats to montane forests in Honduras (Mejia Valdivieso, 2001). The threat of wildfires is particularly high in El Nino years when a decrease in rain accompanied with increased temperatures, increases the amount of combustible dry matter and creates favorable conditions for fires (see Appendix 9 for a summary of the number of wildfires in Central America per year).

Table 15. Areas threatened by wildfires and major ignition sources of wildfire in Central America (Billings y Schmidtke, 2002)

Country	Areas threatened	Major ignition sources
Belize	Pine regeneration Broadleaf in South.	Lighting Milpa burning Hunters
Costa Rica	Protected areas and watersheds Forest restoration areas	Revenge Pyromania Carelessness
El Salvador	Small areas of productive pine forest Fledgling protected areas	Agricultural burning for variety of objectives
Guatemala	Regeneration and commercial forest Protected areas Watersheds	Agricultural burning for a variety of objectives Hunters
Honduras	Regeneration and commercial forest Protected areas Watersheds	Agricultural burning for a variety of objectives
Nicaragua	Pine regeneration Watersheds	Agricultural burning for a variety of objectives
Panama	Pine and teak plantations Protected areas in the canal zone	Agricultural burnings Carelessness Hunting

Effects of agriculture on hydrological patterns

A less direct, but equally important, effect of agriculture on biodiversity is through changes in hydrology, especially patterns of water chemistry, temperature and flow patterns. Since agriculture is dependent on water, in many areas farmers drain wetlands, construct canals or divert water to water crops and animals, highly modifying hydrological patterns. Changes in the vegetation patterns within watersheds may also influence the region's hydrology by changing patterns of runoff and infiltration into the soil and water storage. In general, agriculture reduces rainfall infiltration and water storage, and consequently water flow over soil is much greater and water soil erosion is increased (McNeely and Scherr, 2003).

Indirect effects of agriculture through the accompanying increases in infrastructure

One important indirect effect of agriculture is the expansion of infrastructure (particularly roads) that make the region more accessible (and more attractive) to rural people. As roads are constructed in remote areas and networks appear in natural habitats, invariably these new roads allow landless farmers from other regions to homestead new farms on unclaimed forest land and stimulate the expansion of the agricultural frontier (Geist and Lambin, 2001, 2002). As discussed earlier, the establishment of new roads has accelerated migration to frontier regions and facilitated increased deforestation. For example, a study in the montane

region of Honduras found that most new agricultural plots occurred within 1 km of existing roads or towns, whereas areas that were reforested or under natural regeneration were generally located in areas of poorer access (greater than 1 km from roads; Southworth and Tucker, 2001).

In addition to facilitating agricultural expansion, roads fragment the landscape into sets of smaller patches and provide physical barriers for the movement of wildlife (Matthews *et al.*, 2000). They may adversely affect the abundance and diversity of flora and fauna due to pollution, noise, car accidents and physical barriers (Matthews *et al.*, 2000). Although there are no data on the effects of roads on biodiversity in Central America, the high density of roads in the region (especially in Costa Rica and El Salvador, Table 11) suggest that most regions are vulnerable to these effects. However, the effect of roads on animal species is species-specific and will depend on their ability to cross gaps, their habitat requirements and movement patterns (Matthews *et al.*, 2000).

Factors that influence the impact of agriculture on biodiversity

The relative impact (both spatial and temporal) of agriculture on biodiversity will depend on a variety of factors, including the production system, the management system and the particular landscape context. Different production systems will have distinct impacts on biodiversity due to differences in how these systems are established and their floristic and structural complexity, their productive orientation (Table 16). In particular, the effect of a given system on biodiversity will depend on whether the agricultural system replaces natural habitat, or whether it can be established on previously cultivated land, and whether the system can be cultivated permanently on the same piece of land or whether it requires new land after a few cropping seasons (McNeely and Scherr, 2003; Donald, 2004). Agricultural systems that replace already existing agricultural areas or degraded areas of little conservation value will obviously have a less detrimental effect on biodiversity than those that require the deforestation of natural habitats. In Central America, systems that have been primarily established at the expense of forests include pastures, coffee plantations, banana plantations and small-scale shifting agriculture, whereas other systems

(such as sugarcane or oil palm) have had a lesser total impact on forests as they were established on already deforested land.

Table 16. A qualitative comparison of the relative impact of different production systems on biodiversity through their contribution to deforestation in the area, the level of intensification and agrochemical use, erosion rates, use of fire, and presence of tree cover within the agricultural system (H= high, M= medium and L= low). The column ‘trends in the area affected by this production system’ refers to whether this agricultural activity is currently stable, increasing in area, or decreasing in area. ‘Heterogeneity of matrix’ refers to whether the landscape matrix in which this agricultural system is usually established is highly heterogeneous (i.e. lots of patches of different land uses) or homogenous. Data are qualitative and based on available literature and consultation with experts and should be considered best estimates, rather than strict comparisons, as there is a severe lack of comparative data of environmental impacts of different systems in this region. It is important to also note that the specific impacts of a given production system will depend not only on the system, but the particular biophysical conditions of the site (especially the topography, soil type, and climatic factors), as well as management practices.

Crop	Degree to which it has contributed to	Trends in the area affected by this production system	Use of fungicides	Use of insecticides	Use of herbicides	Use of fertilizers	Overall level of intensification	Use of fire (potential source of anthropogenic fires)	Erosion rates	Fallow presence once a year	Contamination of water	Source of invasive species	Heterogeneity of matrix	Presence of tree cover or natural habitat within these
Beef cattle (extensive production)	H	Stable	L	L	M	L	L	Yes	M to H	No	L	Yes	L	M
Dairy cattle (intensive production)	L	Stable	L	M	M	H	H	No	M	No	M to H	Yes	L to M	L to M
Coffee monocultures (sun coffee)	H	Stable but severely affected by prices	H	M	H	H	H	No	M	No	H	?	L	L
Coffee agroforestry systems	M	Stable but severely affected by prices	M	M	M	M	L	No	L	No	M	?	M	M to H
Cacao agroforestry plantations	L	Decreasing	M	L	L	L to M	L	No	L	No	L	?	M to H	Medium to H
Oil palm	L*	Stable	L	L	L	H	M	No	L	No	H	?	L	L
Maize and other basic grains	M	Stable but under risk if CAFTA	L	H	L	M	L	No	H	Yes	L	?	L-M**	M
Banana plantations	H	Stable	H	H	H	H	H	No	M	No	H	?	L	L
Pineapple plantations	L*	Increasing	L	H	L	H	H	No	H	Yes	H	?	L	L

Rice	L	Decreasing	M	L	H	H	H	No	M	No	H	?	L	L
Sugar cane	M	Stable	L	L	M	H	M	Yes	M to H	Yes	M	?	L	L
Vegetable production	L	Increasing	H	H	H	H	H	No	H	Yes	H	?	M	L
Greenhouses for ferns and flowers	L	Increasing	H	H	H	H	H	N/a	N/a	N/a	H	?	N/a	N/a

* These systems are generally established in previously converted land, rather than in newly deforested areas

** often interspersed with fallows

The particular structural and floristic characteristics of a given agricultural system will also be important. In general, the greater the structural and floristic diversity of agricultural systems (and the more they 'mimic' natural systems), the more biodiversity they support. Consequently, crops such as coffee and cacao that can be grown in agroforestry systems or as polycultures are likely to have more niches and provide more resources for plant and animal species than those that are less structurally and floristically diverse. The species actively maintained within a given agricultural system will also determine the threat by invasive species, though there is insufficient information currently to rank the threat posed by different systems

A second factor that will dictate the impact of agriculture on biodiversity is how the system is managed. For example, the degree to which different production systems demand insecticides, fungicides, herbicides, fertilizers or other chemical inputs will influence the potential severity of nutrient leaching, soil erosion, and water and air pollution. As discussed earlier, crops such as cotton, banana, pineapple, and vegetables which require high levels of pesticides are likely to have a disproportionately high effect on aquatic systems than other less pesticide-intensive systems such as extensive pastures (Figure 7). Systems with high fertilizer use are similarly likely to contribute disproportionately to the eutrophication of streams, rivers and coral reefs.

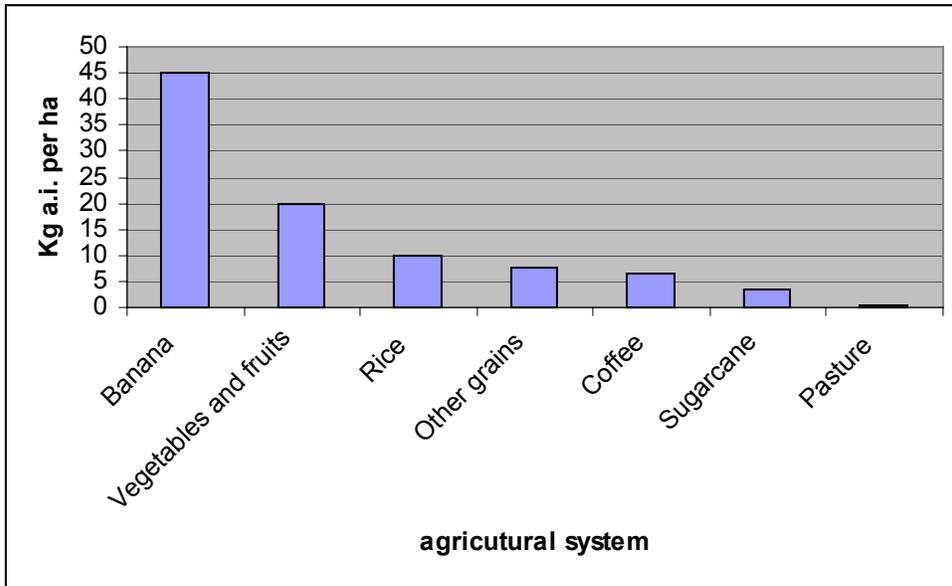


Figure 7. A comparison of the amount of pesticide use (kg of active ingredient per hectare of land use) of the major agricultural crops in Costa Rica (based on Cruz and Castillo, 2000).

Another key management factor is whether or not the agricultural system serves as a source of fires that can affect nearby forests. Fire is a common tool in sugarcane plantations, small-scale agricultural systems, and pastures, and the risk of fire spreading from agricultural areas into protected areas is therefore higher where these agricultural systems predominate. A final management aspect is soil management. Soil erosion problems are also likely to vary across production systems, due to differences in soil management techniques, use of tillage, and/or the types of slopes on which different systems are established. Proximity of different systems to coastal and aquatic systems will also determine the impact these systems potentially have on the sedimentation of aquatic systems.

Finally, the spatial arrangement of agricultural systems in the landscape (particularly the size, shape, location of individual agricultural systems and their relative proximity to natural habitats) will affect the degree to which it impacts biodiversity or can serve as habitat for wildlife. For example, large agricultural plots are likely to have a greater impact on adjacent forests than small plots, just as homogenous agricultural landscapes are likely to have a more negative impact than heterogeneous landscapes which still retain some tree cover. The positioning of individual agricultural systems relative to existing natural areas,

as well as the degree to which these agricultural systems retain any natural habitat, will determine the extent to which it interrupts or facilitates landscape connectivity; similarly its proximity to natural areas can influence spread of exotic organisms, fire, etc.. A good example of the effect of the sizes of agricultural patches on biodiversity comes from studies of shifting agriculture: whereas small patches of shifting agriculture have been shown to have a minimal impact on biodiversity levels, once agriculture becomes more permanent and on a larger-scale, the impact becomes magnified.

Although it is not possible to enter into a more detailed discussion of the different impacts of individual production systems, Table 16 provides a general qualitative summary of the potential effects of different production systems on biodiversity. In addition a summary of the known impacts of four of the region's most important agricultural activities (coffee, banana, cattle production, and sugarcane) is provided in Appendix 10 as an example of the complexity of the effects of agriculture on biodiversity.

Ways of decreasing the advance of the agricultural frontier and of mitigating the impact of agriculture on biodiversity

There are many ways in which the negative impacts of agriculture on biodiversity can be reduced, minimized or even reversed through a combination of macroeconomic, institutional, and microeconomic practices that slow or prevent the advance of the agricultural frontier and technological factors that mitigate the impacts of existing agricultural systems. Efforts to mitigate the negative impacts of agriculture should first focus on protecting the remaining natural habitats and restricting the expansion of the agricultural frontier, to ensure that as much natural habitat as possible is protected. In areas with active agricultural frontiers, the emphasis should be on stabilizing landscapes and stemming the advance of the frontier, whereas in landscapes that are already highly deforested and fragmented, emphasis should be given to preventing the loss of on-farm tree cover (riparian strips, forest fragments, remnant trees, etc.). At the same time, these efforts must also focus on ensuring the adoption of agricultural practices that are sustainable and compatible with biodiversity conservation, and have minimal environmental impact.

However, if these practices are to be adopted, it is critical that they not only promote biodiversity conservation but also fulfill local livelihood needs and be appropriate for the particular socioeconomic conditions of the site of interest.

The mitigation of the impacts of agriculture on biodiversity will require the adoption of technological changes in agricultural systems and landscapes, as well as changes in the management of agricultural systems. While the particular measures appropriate for a given site are likely to be specific (depending on the current land use patterns, climatic and edaphic conditions, the structure and composition of the landscape, the plant and animal communities present and the socioeconomic context, among other factors), a set of general principles for conserving biodiversity within agricultural systems and landscapes has emerged from the complementary disciplines of agroecology, landscape ecology, agroforestry and conservation biology, sustainable rangeland and forest management, and natural resources management (Table 17). What is less clear, however, are the changes that must occur at different levels –macro, micro and institutional- to provide the appropriate context in which these technological changes can be successfully adopted and applied by farmers. In the following sections, we first provide an overview of the large menu of technological options that can help minimize the direct and indirect impacts of agriculture on biodiversity – dividing them into three main categories- changes in production systems, changes in management practices and changes in the way agricultural landscapes are structured. Although we present these principles below as separate entities, they interact in many ways and a combination of these different approaches is likely to be the most effective strategy for conservation efforts. We then discuss the macroeconomic, institutional and microeconomic changes which could help facilitate the adoption, promotion and implementation of these mitigating practices.

Table 17. A summary of the available technological strategies for mitigating the impact of agriculture on biodiversity loss through changes in the agricultural systems, their management, and the landscapes they comprise.

Scales of change	Changes in agricultural land use at the farm level	Changes in management practices	Changes in the configuration of agricultural landscapes
	Promote changes from high impact to low impact production systems	Reduce and minimize use of pesticides through: - more efficient use and application of agrochemicals - adoption of alternative production systems requiring fewer pesticides - adoption of organic agriculture - use of integrated pest management strategies - diversified production systems that maintain intact insect populations and thereby reduce the need for pesticide use	Position crop fields, pastures and other agricultural production areas on areas that have the appropriate soils, slopes and condition for production, and leave more fragile or areas that are unsuitable for cultivation in natural habitat
Specific actions	Diversify agricultural systems (using polycultures, intercropping, greater variety of crop types, agroforestry systems, etc.)	Reduce entry of agricultural pollutants and sediments into streams through: -reduced pesticide and chemical use (see previous point) -careful location of point sources of contaminants away from rivers and watercourses -use of physical and vegetative conservation structures as filters to protect streams from agricultural pollution -targeted application of agrochemicals	Include natural habitats within agricultural landscapes as habitats and resources for wildlife by: -conserving and protecting remaining areas of natural vegetation (forest patches, riparian areas, etc.) in and around agricultural landscapes through the creation of on-farm reserves, set asides, conservation easements or other protective mechanisms -restoring natural vegetation in degraded, fragile or unproductive areas through natural regeneration, reforestation and/or enrichment planting

Technological changes

Changes in land use at the farm level

The most fundamental change which could help mitigate the impacts of agriculture on biodiversity is the change from conventional agricultural systems that have a strong negative impact on biodiversity and the environment, to systems that are more environmentally benign. As discussed earlier (Table 16), different agricultural systems vary

in the extent to which they affect biodiversity and consequently the replacement of the more detrimental systems with more benign systems is likely to benefit conservation efforts. For example, the conversion of large expanses of banana plantations (with the accompanying high levels of soil and water pollution by agrochemicals) to land uses that use fewer agrochemical inputs is likely to have a positive effect on biodiversity conservation.

In general, there is a need to move from intensive, high input, monocrop production systems towards more diversified systems which require fewer inputs, are less intensively managed and are ecologically-sound (Pagiola *et al.*, 1997; McNeely and Scherr, 2003). Such changes could reduce the negative impact of biodiversity through agrochemical pollution, soil erosion and habitat loss, and at the same time provide habitat and space for wildlife within agricultural systems. For example, the conversion of open grown coffee plantations to agroforestry systems is likely to not only reduce contamination of soil and water by pesticides, fertilizers and sediments, but also provide trees and other plant cover that can serve as habitat for wildlife (Perfecto *et al.*, 1996; Somarriba *et al.*, 2004 and references therein). In general, the adoption of agroforestry systems (which combine a tree or shrub component with crops and/or livestock, either in the same piece of land, or sequentially), polyculture cropping systems, intercropping, organic farming, and crop rotation, or other practices that diversify agricultural production and reduce the need for agrochemical inputs are likely to favorably impact biodiversity conservation at the local scale (Schroth *et al.* 2004; Somarriba *et al.*, 2004). Whenever possible, these systems should be designed based on agroecological principles and in as much as possible, mimic natural systems so that they can fulfill many of the same ecological functions (Altieri, 1995).

Changes in agricultural practices

Changes in the way in which agricultural systems are managed may also benefit conservation efforts by reducing the frequency and use of agrochemicals, improving waste management and the contamination of waterways, minimizing soil erosion and sedimentation, and increasing habitat and resources of wildlife within agricultural systems. Modifications in the management of soils, water, vegetation and livestock practices, range

from changes in the frequency and timing of management practices, to more fundamental changes in the way in which agriculture is practiced. Management strategies which have been documented to have a minimal negative effect on biodiversity include intercropping, no-till operations, ecological soil and water management practices, tillage practices, use of cover crops, manures and improved fallow, crop diversification, integrated pest management, organic farming, reductions in livestock stocking rates in fragile lands, and the elimination of human-made fires (McNeely and Scherr, 2004; Clay, 2004).

Numerous strategies exist for reducing the use of agrochemicals, including the use of more efficient and better application of pesticides and fertilizers to fields and farms, the use of integrated pest management strategies, the adoption of organic agriculture practices, and the use of plants that have been bred for pest and disease resistance and require less chemical control, and innovative planting patterns that facilitate natural pest control. In integrated pest management, farmers keep track of pest populations and apply pesticides strategically when pest levels pass above a certain threshold; they also combine the use of pesticide with biological controls (introduction of parasitic species or predators that control pest populations) or through cultural controls (management practices that create habitat conditions that are adverse to pests or create habitat that favor parasitic and predator species), thereby reducing the need for heavy pesticide application. In organic agriculture, in contrast, farmers replace chemical fertilizer inputs with organic sources of nutrients (such as animal manures, green manures, and composts) and practices that favor nitrogen fixation by soil microorganisms, and rely on cultural controls and biological controls to control pest problems, rather than using pesticides (García, 1999).

In addition to finding ways of reducing the use of agricultural pollutants, it is necessary to prevent their entry into streams and aquatic systems. Point sources of pollutants (such as barnyard areas, or sheds containing chemicals, or coffee processing plants) can be located away from streams and rivers to minimize the risk that these pollutants enter waterways and affect water quality. Actions can be taken to ensure the appropriate use and application of agrochemicals and contaminants on fields (e.g. only using the quantity of agrochemicals that will be absorbed by the crop or grass, applying only where there is no rain so to minimize runoff, reducing the amount used, or applying the chemicals more efficiently so that there is less runoff) will also reduce the pollution of waterways. Finally, vegetative

buffer zones can be established to act as filters and prevent pollutants and sediments from reaching streams and rivers (McNeely and Scherr, 2003).

The pollution of streams and watercourses by sediments can similarly be minimized through the adoption of soil-conservation techniques (e.g. use of cover crops, mulches, terracing, windbreaks, etc.), which reduce soil loss to wind and water and through the careful management of soil resources (Pimentel *et al.* 1995; 1999). In heavily grazed areas where erosion rates are high, changes in animal stocking rates may help reduce soil compaction and loss, and in doing so, reduce the amount of sediments entering rivers. On the other hand, soil erosion in crop fields may be minimized by ensuring that the soil is covered with crops or residues year-round (i.e. preventing the burning or elimination of crop residues after harvesting), and by using minimal or no-till practices.

Another strategy that can enhance biodiversity conservation within agricultural plots is to manage these systems so that they provide habitat and resources for wildlife (Rice and Greenberg, 2000). Many of the management strategies already discussed which reduce agricultural and sediment pollution, at the same time create niches that allow wild plants and animals to occur within the agricultural landscape. The presence of weeds, epiphytes, lianas, shrubs and other vegetation that spontaneously arises in crop fields and pastures is often beneficial to biodiversity conservation, providing shelter, nesting and reproduction sites for insects, birds, and amphibians, as well as providing flower and fruit resources, and can be managed for conservation goals by minimizing the frequency or intensity of weed removal or trimming, and ensuring that at least some areas with vegetation to remain within the agricultural landscape (Harvey *et al.*, in press). Other management strategies that can enhance the value of agricultural landscapes as habitats include the retention of dead branches, snags and fallen trees within agricultural plots, as these provide habitat and resources for many insects, amphibians and other organisms, and reductions in the frequency and intensity of disturbances (such as fire, harvesting and pruning). For example, in crops that require pruning, care should be taken to prune at a time of year when habitats and food is not limiting so that the removal of branches, flowers and fruits has a less drastic impact on the populations that use these resources. A summary of the best management practices for particular crops (based on Clay, 2004) is provided in Appendix 11.

Changes in the configuration of agricultural landscapes

A final strategy for minimizing the impact of agriculture on biodiversity conservation is through the careful design and planning at the farm and landscape level, with the explicit goals of conserving biodiversity and maintaining ecological integrity. This whole-farm and whole-landscape planning approach should focus around three main issues: 1) carefully identifying and designating areas that are appropriate for agricultural production and leaving other areas as natural vegetation; 2) including natural habitats within farms and agricultural landscapes to serve as habitats and resources for wildlife; and 3) ensuring landscape connectivity by creating habitat networks and corridors across the agricultural landscape.

At the foundation of this landscape-level planning is the need to carefully position production systems on appropriate sections of the landscape with soils, slopes and microclimatic conditions that can support agricultural production. The particular selection of crops and production systems should be tailored to the particular edaphic and ecological conditions of the site, and if done correctly, can minimize soil degradation and soil erosion and minimize negative impacts on biodiversity, while also contributing to sustainable production. Fragile areas – such as areas with steep slopes, poor soils or high levels of degradation or areas that are critical to conservation efforts (either due to the presence of endemic species or threatened ecosystems), should be allowed to remain under natural vegetation, whenever possible (ESA, 2000).

A second critical element of landscape level planning with explicit biodiversity conservation goals is the retention of natural habitats within farms and agricultural landscapes which can serve as sites for foraging, reproduction and shelter. Conservation efforts should first focus on identifying and conserving the natural vegetation which already exists in agricultural landscapes. Most agricultural landscapes in Central America- with the exception of areas dedicated to pineapple, banana, sugarcane or rice contain areas that are not farmed and retain a significant amount of natural vegetation (albeit highly modified), in the form of riparian forests, small forest fragments, dispersed trees, abandoned areas, and uncultivated strips along field borders. Although these habitats are usually overlooked in conservation planning, they may play important roles in mitigating the impact of

agriculture on biodiversity, as even small forest fragments, narrow riparian forests and isolated trees in pastures have been shown to be of important conservation value (Guindon, 1996; Harvey and Haber, 1999; Ricketts *et al.*, 2000) providing important habitats and resources of wildlife, even if at small spatial scales. Where natural vegetation still occurs on farms, the first priority must therefore be to ensure its protection as habitat for wild biodiversity, whether through legal mechanisms such as the designation of small private reserves (e.g. Langholz *et al.* 2000), protected areas, conservation easements or set-asides, or simpler management practices such as the fencing off of these areas to prevent cattle entry. In areas where there is little remaining natural vegetation, alternative strategies to re-introduce natural vegetation into agricultural landscapes are necessary, such as the establishment of plantations and agroforestry systems (preferably of native species). Tree cover can also be enhanced through allowing areas to revert back into forest through natural regeneration. Areas that have been highly degraded within landscapes and that currently serve neither conservation nor productive purposes should be restored, either through active planting of natural vegetation, enrichment planting, or through natural regeneration. In some cases, the establishment of rapidly-growing, non-native plantations can act as a catalyst for natural regeneration of native species (Parrotta *et al.*, 1997; Guariguata *et al.*, 1995; Lugo 1997) and may facilitate the restoration process, however care has to be taken that these non-native species do not spread and become invasive. The careful design and spatial arrangement of agricultural systems within landscapes to provide natural habitat for species that prey on pest organisms will also greatly reduce or eliminate the need for pesticide use.

The final element of landscape-level planning is to position natural habitats within the agricultural matrix in such a way as to most enhance the physical and functional connectivity of the agricultural landscape, and allow ecological processes such as seed dispersal, pollination and animal movement (Turner *et al.*, 2001). This connectivity may be obtained in a variety of ways, including the use of linear plantings or linear elements (e.g. riparian forests, windbreaks or live fences) as physical corridors, the retention of scattered or grouped trees in agricultural landscapes that serve as stepping-stones, or the creation of a heterogeneous agricultural matrix that is more hospitable to animal movement. In general, agricultural landscapes that have a greater variety of land use types, smaller patches (with large areas being divided by hedgerows, windbreaks, live fences or remnant natural

vegetation) and a more heterogeneous mixture of natural and agricultural land use are thought to be more favorable for biodiversity conservation than homogenous landscapes consisting mainly of monocrops (Guevara, 1995; Chacon, 2004; Harvey *et al.*, in press;). Increasing numbers of studies have also demonstrated that the presence of a network of natural habitats and on-farm tree cover within agricultural landscapes may facilitate the movement of birds, bats and other organisms across agricultural landscape, and it is likely that this maintenance of landscape connectivity prevents the loss of species and genetic diversity (Bierregaard *et al.*, 2001; Daily *et al.* 2003). Links between protected areas and remaining natural habitats on surrounding agricultural landscapes are particularly critical for conservation efforts for many species that require large habitats or make seasonal migrations between distinct areas. For example, in Monteverde, Costa Rica, the presence of isolated trees and small forest fragments in pastures on the Pacific slope are critical to the conservation of the three-wattled Bellbird and the resplendent quetzal (Guindon, 1996; Harvey *et al.*, 2000). Finally, landscape connectivity can also be enhanced by identifying and removing barriers to animal movement (such as infrastructure or certain cropping systems) within agricultural landscapes. A good example of the application of this ecological and landscape-level approach to landscape planning lies behind the Mesoamerican Biological Corridor Project which is attempting to connect protected areas through Mesoamerica through the sustainable use of agricultural landscapes, including management of the agricultural matrix, restoration and reforestation strategies (Miller *et al.*, 2001).

Regulatory, institutional and market based interventions

Because of the variety and complexity of the underlying causes of agriculture's negative effects on biodiversity in Central America, intervention measures aimed at mitigating or eliminating these affects must be addressing from varying approaches, including changes in regulatory framework, institutional support and market based interventions. The goal of these measures should be to decrease the advance of the agricultural frontier and the loss of additional natural habitat, while also promoting the use of sustainable, and less environmentally detrimental practices on existing agricultural lands. In addition, it is

critical that these measures consider the tradeoffs between achieving biodiversity conservation goals, on the one hand, and fulfilling food, land and income generation needs of the growing Central American population. It is therefore important to seek scenarios with ‘win-win’ outcomes or situations where interventions improve conservation efforts without adversely affecting local socioeconomic conditions or, preferably actually lead to positive impacts on local conditions. Formulating policies that promote the enactment of principles leading to biodiversity preservation therefore requires a consistent evaluation of their effectiveness, of the costs associated with their implementation, and of the possible effects on the human populations concerned. The political viability of the proposals must also be evaluated, especially given the backdrop of extreme poverty, populist governments, open trade, inequitable wealth distribution and the existence of special interest groups, in the region. With these caveats in mind, we present a series of possible interventions: regulatory framework and institutional support as well as market based approaches (Table 18).

Table 18. Summary of key regulatory, institutional and market based interventions that could help mitigate the impact of agriculture on biodiversity conservation in Central America.

Regulatory and Institutional	Market based
Establish secure property rights	Increase the value of forests and other natural habitats and their products through:
Eliminate perverse incentives that accentuate forest clearance and unsustainable agricultural practices	Certification schemes for sustainable timber production and sustainable agriculture
Strengthen legal framework for protection of forests, protected areas and buffer zones	Markets for non-timber forest products
Do not recognize land rights of squatters invading protected areas	Payment for environmental services
Create strategic alliances to improve planning and management of protected areas	Bioprospecting
Develop private reserves in agricultural landscapes	Ecotourism
Train public institutions, NGO’s and government extension agencies in sustainable agriculture and promote its adoption	Application of instruments such as the clean development mechanism to invest in forest and reforestation projects
Develop local capacity in natural resource decision-making	

Institutional support and regulatory interventions

At the macroeconomic level, the reduction of deforestation could theoretically be addressed by the design of population control policies, the imposition of limits on economic growth or adoption of policies that avoid undervaluation of local currency and inflation, and the adoption of market and trade policies that incorporate ecological concerns and thereby reduce the need to exploit the remaining forested areas; however in practice, these interventions are extremely difficult to design and unlikely to be implemented. The only practical course of action is to raise politicians' awareness of how their microeconomic policy decisions may impact the region's natural capital and biodiversity and to seek local or regional initiatives that mitigate the negative impact of such policies (Thorpe, 1997; Kaimowitz *et al.*, 1998; Thrupp, 1998).

While it is difficult to adopt sweeping, overarching macroeconomic policies that stem the advance of the agricultural frontier, there are some individual interventions which hold promise for mitigating the environmental impact of agriculture and stabilizing agriculture at the forest frontier. These include the variation of the legal framework in terms of establishment of secure land property rights, the progressive elimination of perverse incentives (such as subsidized irrigation water, crop credits and insurance schemes that promote the use of agrochemically-intensive technological packages) and customs protection for environmentally damaging products, among others. Regulations that ensure that those that pollute are responsible for assuming this cost represent a immediate alternative to mitigate the problem of pesticide contamination of water, for example. Changes in property rights should include eliminating laws that require farmers to convert forests to agriculture to obtain land ownership, modernizing current land registration systems, resolving existing agrarian dispute processes, initiating well-designed and executed agrarian reform processes, and recognize the collective property rights of indigenous or peasant populations

The region should strengthen the legal framework needed to protect the remaining forested areas, protected areas and their buffer zones (thereby more effectively protecting the remaining forests and natural areas), and ensure that local institutions have the necessary skills and capacity to promote sustainable agricultural practices and to effectively evaluate both the ecological and social impacts of different resource management strategies. The

legal framework for forest protection should include sanctions and controls that discourage additional deforestation or the entrance of illegal squatters into reserve or national parks, prevent the expansion of agriculture into reserve areas, and consolidate and improve national park management. Such a framework will require strategic alliances between both national and international institutions working on conservation issues and natural resource management, at both local and regional levels. One good example of such an effort is PROARCA (the Protected Areas Component of the USAID-funded Central American Environmental Program), an alliance which has developed among institutions in the Gulf of Honduras (Belize, Guatemala, Honduras), Gulf of Fonseca (El Salvador, Honduras, Nicaragua), La Mosquitia (Honduras and Nicaragua) and Amistad-Cahuita-Rio Cañas (Costa Rica, Panama), to share management responsibilities, improve financial management and enhance eco-regional planning within the Mesoamerican corridor and regional protected areas.

Institutional efforts to conserve remaining natural habitats could also be achieved through the establishment of private conservation areas, which could complement the State national parks model. For example, the Costa Rican government established a program of this type in 1992, which forces private conservation efforts to comply with certain soil use and conservation norms, in return for land tax exemptions, technical assistance, and help in the case of squatter invasions. This program appears to be quite successful (by 2000, the program had achieved the establishment of 22 private protected areas, covering 6311 ha; Langholz *et al.*, 2000) and could be a model for other countries.

In addition to efforts that aim to protect the remaining forested areas, institutions should also place emphasis on attaining sufficient technical capacity to adopt practices that mitigate the effects of existing agricultural systems on biodiversity conservation. One potentially effective policy, both in the short and medium term, is the training of public institutions, NGOs or farmer organizations in soil conservation practices, organic agriculture, integrated pest management (IPM), sustainable forest management, and agroforestry systems, among other tools. Participatory extension processes such as the CATIE-MIP-NORAD program in Nicaragua (which promoted the use of integrated pest management coffee, vegetables, basic grains, and Musaceae through innovative, participatory programs with farmers) exemplify the type of efforts and programs required.

Actions must also be taken to create institutional moulds and local capacities that enable all stakeholders to become involved in decision-making processes that affect the natural resource base. In Central America, there is some evidence that community forest management through concessions has been successful in avoiding the unchecked growth of the agricultural frontier in Petén, Guatemala (Prins, 2001). Likewise, incentives to achieve sustainable forest management may include forming firefighting community brigades using combat, detection and prevention systems. The active participation of all relevant stakeholders in decision-making processes and the use of conflict management resolution mechanisms could represent an effective strategy to solve conflicts over natural resource use.

Another priority is to promote inter-institutional collaboration to provide alternative, accessible and profitable technology options to producers in the region, and seek innovative ways of promoting sustainable agricultural land practices. The Program for Sustainable Agriculture in Hillsides in Central America (PASOLAC) is an interesting example where the public, private, and trade union sectors are jointly working towards the dissemination of sustainable soil and water management technologies among small producers on the Nicaraguan, El Salvadorian and Honduran hillsides. Another interesting example is the Reventazon River Watershed Management Unit (UMCRE-ICE) where governmental and non-governmental institutions and civil society groups have joined efforts to protect the Reventazon river watershed in Costa Rica, by promoting the adoption of sustainable agricultural practices (such as silvopastoral systems, reforestation of degraded areas, recycling of animal wastes, integrated pest management, among others) which not only reduces the impact of agriculture on the remaining biodiversity, but may also be profitable for farmers.

Market based approaches

It is important to adopt strategies that specifically recognize the value of biodiversity and incorporate this value into market transactions. An increased value of forests and their products promises specific positive effects on biodiversity preservation in the region. The value of biodiversity could be increased in several ways, by obtaining higher prices for timber and other non timber forest products, providing payments for environmental services

(water, carbon sequestration) to farms that maintain forests and other natural habitats, developing ecotourism in natural and agricultural areas, and establishing bioprospecting agreements.

Although in the short term increased timber prices could be a strong incentive to overexploit the remaining forests, in the long term it is a necessary condition for financially sustainable forest management (Kaimowitz *et al.* 1998). Certification strategies for environmentally produced products and long term secure forest concessions can facilitate better prices or preferential market access for forest products. However, the effectiveness of this strategy is dependent on the existence of market niches for certified products, and their widespread use by the timber, construction and furniture making sectors. WWF is promoting FSC certified wood among private and community producers, and to date, has certified a total 732,864 ha in 42 forestry operations comprising plantations and natural forests (WWFCA, 2004). Certification can also promote sustainable agricultural practices in the region. For example, the Rainforest Alliance has certified a total of 62,540 ha of agricultural land in Central America, primarily in banana and coffee plantations (Table 19); however more recently it has also begun certification of citrus plantations and flower and foliage production systems. Although the precise certification criteria vary across products, the certification schemes address human welfare and economic concerns and promote the use of best management strategies that minimize the impact of agriculture on the surrounding landscape. Other similar certification schemes that seek to promote sustainable agriculture and land use management include ‘bird-friendly coffee’ (SMBC, 1999), and organic agriculture certification schemes.

Table 19. Summary of the total area (in hectares) of farms in Central America certified by the Rainforest Alliance, as of May, 2004.

Country	Bananas	Citrus	Coffee	Flowers and foliage	Total area
Costa Rica	16,710	7,050	2,549	516	26,825
El Salvador	2840				2840
Guatemala	6,084		5,210		11,293
Honduras	4,708		1,000		5,708
Nicaragua	586		1,138		1,724
Panama	12,437		1,713		14,150
Total	43,365	7,050	11,610	516	62,540

Source: <http://rainforest-alliance.org/programs/cap/farm-list.pdf>

An additional way to increase the value of maintaining forests instead of turning them into agricultural lands is to provide markets for new non-timber forest products that can be sustainably harvested. This strategy is being promoted by numerous institutions, including Cultural Survival Enterprises, Conservation International and the World Bank, which incorporate the search for and commercial development of non-timber forest products into many of their conservation and development projects (Kaimowitz *et al.*, 1998).

The payment for environment services is another market intervention instrument that acknowledges the value of forests, forest plantations and agroforestry systems in providing environmental services that benefit society as a whole. In Costa Rica, for example, the Forestry Law N° 7575 establishes the possibility of making this sort of payments to landowners for the environmental services (biodiversity conservation, water conservation, carbon sequestration, and maintenance of scenic beauty) provided by forests, forest plantations and agroforestry system, using money collected from the gasoline tax. By 2003, environmental service payments were already being applied to 66,911 ha in Costa Rica, and the scheme is expected to grow in order to promote the conservation of private forests in the Osa Conservation Area, Tortuguero and Amistad Caribe, which are a priority for the Mesoamerican Biological Corridor. Likewise, initiatives such as the Small Grants Programme (UNDP-GEF) have allowed Costa Rican indigenous territories to access to payments for environmental services. The use of environmental services may constitute the

starting point for other Central American indigenous communities hosting many natural forest remnants to access forest conservation incentives.

Carefully planned and implemented ecotourism can also play a crucial role in the conservation of natural landscapes in Central America, with the benefits derived from regulated tourist activities often acting as a barrier to increased agricultural activities and additional deforestation. An interesting, recent development is the creation of eco-tourism certification schemes ('smart voyager') by the Rainforest Alliance Sustainable Tourism program, that assure travelers that the ecotourism ventures meet both environmental and social criteria, and have a minimal impact on the environment (Rainforest Alliance web page, <http://rainforest-alliance.org/rograms/sv/index/html>). Similar, local schemes are also appearing, such as the Talamanca Agroecotourism Network and the Community Tourism Network, both in Costa Rica, which impose quality criteria for their products and services (PROARCA, 2002).

Another way in which value can be added to natural resources is by establishing agreements for bioprospecting, i.e. the search for new sources of chemical compounds, genes, proteins, microorganisms and other elements existing in biodiversity that possess real or potential economic value (INBio, 2004). The agreements reached by INBio in Costa Rica with international pharmaceutical and agroindustrial companies illustrate the potential value of these agreements (with royalties going to protect conservation areas, develop new projects and improve national technological capability, INBio, 2004), however this mechanism has generated considerable controversy about the rights and responsibilities associated with biodiversity conservation and use.

A final way in which Central American countries may be able to add value to forest habitats and generate income to conserve natural resources is through the Clean Development Mechanism (CDM) of the Kyoto Protocol, which allows developed countries to invest in forest and energy projects in developing ones, in exchange for emission reduction certificates. However, since it is not yet clear how the CDM will be implemented, how credits will be measured and how emission reductions certified, the full potential of this scheme for Central American countries is still open to debate.

Conclusions and recommendations

1. Agriculture has historically had an important negative impact on biodiversity conservation in the region primarily through the expansion of the agricultural frontier at the expense of natural habitats.
 - a. The history of agricultural expansion and the current patterns of land use are intricately linked to the history of four main agricultural commodities (cattle, coffee, banana and sugarcane), all of which are produced for export. These commodities provided the stimulus for deforestation and conversion of forests to agricultural land use, and continue to be the dominant crops in the region.
 - b. Local governments have openly promoted and facilitated the expansion of these agricultural commodities, at the expense of natural habitat, through active colonization programs, credit schemes, subsidies, and protective trade barriers, among other factors. The conversion of forest to these agricultural commodities was viewed by most governments as a means of achieving development goals, and little attention was paid to the accompanying environmental costs of this expansion.

2. Today, the nature of the threat of agriculture to biodiversity conservation has changed. While agriculture continues to drive deforestation in the few remaining, remote areas where the agricultural frontier still exists, the main impact of agriculture is now due to the intensification of existing agricultural systems (and the concurrent increased use of pesticides, fertilizers and other inputs, the loss of hedgerows/live fences and natural habitat within these systems and the greater pressure on the remaining natural resources) and to a lesser degree, changes in the types and arrangement of agricultural systems within landscapes (particularly the trend from heterogeneous to homogenous landscapes, and from small, subsistence level plots to larger industrial plantations).

3. A wide array of social, economic and institutional factors have contributed to the expansion of the agricultural frontier, the intensification of existing agricultural systems and changes in agricultural landscapes. These include demographic and social factors, poverty levels, land tenure, government policies and laws, international prices and consumption tendencies, expansion of available infrastructure, market failures, technological factors, subsidies and tariff protection, and gaps in information and extension services, among other factors.
 - a. The interactions between these factors is complex and there are likely to be complex feedbacks, synergisms, etc, which make it difficult to single out any particular factor as being more critical than others
 - b. It is important to note, however, that many of the factors driving the changes in Central American agriculture are external to the region and are therefore difficult to influence. The region is particularly vulnerable to fluctuations in international prices for its main agricultural export commodities- coffee, banana, sugarcane and meat.

4. One factor which may significantly impact agricultural activities in the region in future years is the adoption of CAFTA (the Central American Free Trade Agreement). If this agreement is ratified, individual countries will have to comply with local environmental and labor regulations, including norms on the use of agrochemicals, protection of riparian forests, and resource management etc. Since most Central America countries have fairly advanced and rigorous environmental laws which are usually not fully enforced, this means that environmental conditions are likely to improve in the short run. Because CAFTA will create markets for some agricultural products but negatively affect markets of others (with the particular outcome being case specific for individual countries and agricultural commodities), its adoption is also likely to lead to dramatic changes in the agricultural commodities cultivated and in the composition and structure of agricultural landscapes- which in turn, may have either positive or negative effects for biodiversity depending on the resulting types and arrangements of production systems. CAFTA may also have important social and economic impacts that affect agricultural production and biodiversity conservation.

5. Different agricultural production systems vary in the extent to which they affect biodiversity, due to differences in their requirement for new cleared land, pesticide and fertilizer use, susceptibility to soil erosion, cropping intensity, area occupied, and spatial configuration in the landscape, among other factors. The effect of different production systems is also likely to be site-specific, depending on the particular social, economic, ecological and biophysical conditions.

6. Although the multiple ways in which different production systems impact biodiversity makes it difficult to compare across systems or sites, four production systems (bananas, coffee, cattle and sugarcane) have historically had a greater impact on the environment than others due to the degree to which they fueled widespread deforestation.
 - a. Banana production has had a serious impact on the Caribbean lowlands due to the deforestation of large areas and the high use of pesticides and fertilizers that contaminate aquatic and soil communities.
 - b. Extensive cattle production has resulted in deforestation of large areas throughout the region, but particularly in both the Pacific and Caribbean lowlands.
 - c. Coffee production has had a disproportionate effect in the highlands of Central America, where climatic conditions are most favorable for coffee growth.
 - d. Sugarcane production has contributed significantly to the loss of forest cover in the Pacific lowlands and continues to impact natural communities through herbicide and fertilizer runoff, soil erosion, and escaped fires.

7. In the future, coffee, cattle, banana and sugarcane production systems are likely to continue to have a large impact on biodiversity, primarily due to the large area they continue to occupy, although the relative importance of individual export commodities may fluctuate over time in response to changes in prices. However, new production systems (vegetable and fruit production systems which require

heavy fertilizer and pesticide use) may gain importance in future years and pose new challenges for conservation efforts.

8. Differences in management practices (e.g. organic/conventional; integrated pest management) vs. conventional pest use, polycultures vs. monocultures) influence the degree to which an individual production system impacts biodiversity both onsite and offsite, as do differences in the spatial composition and structure of agricultural landscapes.
 - a. Studies from other regions indicate that polycultures conserve more on-site biodiversity than monocultures, that organic agriculture has a lesser environmental impact than conventional agriculture and that IPM is a superior alternative to conventional pest use, however there is little specific data on these differences from within Central America
 - b. Landscapes which retain a higher degree of tree cover and natural habitats (e.g. small forest patches, riparian areas, dispersed trees, live fences, etc.) and are more heterogeneous (with smaller patches and a greater variety of patch types) will be of greater biodiversity conservation value than simplified, homogenous landscapes lacking natural vegetation.
9. Efforts to mitigate the impact of agriculture on biodiversity should focus not only on ensuring that agriculture does not extend into existing protected areas or remaining remnants of natural habitats, but also on finding ways to intensify production systems without the associated negative impacts on biodiversity and encourage landscape-level changes which positively affect conservation efforts.
 - a. There are many known ways of enhancing the conservation value of individual production systems, applying environmentally-friendly management practices or designing and managing agricultural landscapes for conservation goals, which could be readily applied to the Central American region.
 - b. There are also many opportunities for mitigating the impact of agriculture on biodiversity through regulatory, institutional and market-based factors,

however these issues are complex and not easily or quickly resolved without considerable political will and government intervention.

- c. The key issue is how to create the appropriate incentives, policies, laws and socioeconomic conditions under which these sustainable practices can be applied.

10. Successful mitigation of the environmental impact caused by agriculture requires an intelligent mix of incentives to adopt environmentally friendly agricultural practices and suitable technological developments as well as mechanisms that stem the further expansion of the agricultural frontier. The goal is to achieve a balance between the need for increased agricultural productivity to feed a growing population on one hand, with the need to protect the biodiversity and environmental services from natural habitats on the other hand.

Research needs

While it is clear that agriculture has dramatically modified the natural landscape in Central America, there are still many unknowns about the ecological footprint of the agriculture in the region. A better understanding of the links (and potential feedbacks) between social, economic and institutional factors, agricultural systems and biodiversity is critical if the impact of agriculture on biodiversity is to be successfully abated and mitigated. Here we present a brief overview of the main areas where specific information for Central America is currently inadequate or missing.

One clear information gap is the lack of readily available and detailed information on the spatial distribution of ecosystems and different land uses within the region and how these patterns change over time. Although maps are available of the major ecoregion types, they often do not indicate the amount of natural habitat remaining within the ecoregion, the degree of habitat fragmentation, or the land use surrounding natural habitats, and this makes it difficult to assess which agricultural land uses are encroaching on natural habitat, though there are some exceptions (Kappelle *et al.*, 2003). Maps of forest cover should indicate not only how much forest area remains, but also identify the sizes and shapes of remaining forest patches, the habitat that surrounds them, the pressures facing the forests

and their conservation status (Logsdon *et al.*, 1996; Woods *et al.*, 2000). In addition, there are currently no complete, detailed maps showing the different land uses within the region. Better information on the distribution of different agricultural production systems (including information on resource management aspects such as whether organic, agroforestry or integrated pest management practices are used, information on land ownership patterns, and information on whether the system is orientated for subsistence or export) and the dynamics of land use (including information on land use flux and spatial shifts in agricultural expansion, abandonment and conversion) would provide a more accurate view of how the structure and composition of individual landscapes are changing over time due to agricultural practices (Matthews *et al.*, 2000; Wood *et al.*, 2000; Logsdon *et al.*, 2001). Armed with this knowledge, land managers could better assess which agricultural activities are directly affecting adjacent natural habitats and the nature of these impacts, and use this information to design mitigation strategies that are most appropriate to the particular conditions of the landscape of interest (Logsdon *et al.*, 2001).

A second area that requires additional research are studies of the specific ways in which agriculture contributes to biodiversity loss or maintenance. Although there are many studies from other regions that document the ways in which agriculture affects biodiversity (through deforestation, forest fragmentation, pesticide use, soil erosion and sedimentation, agricultural fires, changes in hydrological patterns, introduction of invasive species, etc.) detailed studies from Central America are woefully lacking. More rigorous studies are required to carefully document both the individual and cumulative effects of these agricultural practices on the composition, species richness and abundance of natural communities, as well as on the ecosystem services they provide. In particular, studies should assess the direct impact of agriculture by studying animal and plant communities before and after their conversion to agriculture and by monitoring communities in agricultural landscapes over time. The few studies that have assessed biodiversity within agricultural landscapes in Central America were conducted on short temporal scales and limited spatial scales, making it difficult to know the cumulative and long-term effect of agriculture on natural communities. Of particular concern is the lack of studies on the distribution and effects of pesticides in and their effects on tropical aquatic ecosystems (de la Cruz and Castillo, 2000) and the lack of information on invasive species (Hernández *et al.*, 2002).

A third key area for future research is the specific comparison of the effects of different agricultural systems and/or different management practices on both the local and regional biodiversity. Little information is currently available to assess the cumulative impact of any agricultural system in a specific location over time, and still less information is available on the comparative ecological impact of different systems that can be established under the same conditions. In addition, there have been remarkably few studies that have compared alternative management strategies (e.g. organic vs. conventional, integrated pest management vs. agrochemical use, etc.). This lack of information is not specific to Central America: Clay (2004, p.10) in a global review of the effects of different agricultural commodities concludes that “little work has been undertaken to assess the cumulative environmental impact of any single crop in a specific place over time, more less the comparative impacts of crops that produce products that are readily substituted for each other. Even less has been done to evaluate the global impacts of a specific crop or to identify the likely environmental impacts of global trends within an industry”.

Another important gap is the lack of studies that document how the adoption of better management practices (e.g. reduced pesticide use, integrated pest management, adoption of agroforestry systems or organic production) affects not only biodiversity conservation, but also the social and economic conditions of the farming communities in which they are promoted. Although many projects and NGO’s have widely promoted the use of these more environmentally friendly practices, there is surprisingly little information available on whether these practices actually help stem the advance of the agricultural frontier, provide additional habitat and resource that enable wildlife to be maintained within agricultural landscapes, or mitigate the negative effects of pesticides, fertilizer use and fires on natural communities. There is an urgent need to quantify the impacts of these proposed mitigation strategies on biodiversity conservation (measured in terms of overall diversity, or in terms of increases in population size of threatened species or enhanced movement across the agricultural matrix). At the same time, information on the factors that affect the adoption of mitigation strategies (cost/benefits, feasibility, ease of adoption, etc.) is needed to better orientate strategies that are likely to be appropriate for a given socioeconomic and ecological context. Equally important, there is often little information on the social and economic costs and/or benefits of particular mitigation strategies to farming communities.

Since farmers generally only adopt new agricultural systems or practices if they are culturally and socially acceptable and economically beneficial, it is important that any proposed mitigation strategies be viable socially and economically, as well as ecologically. Any analysis of proposed mitigation strategies must therefore clearly outline both the costs and benefits of the proposed mitigation strategy compared to the conventional, existing practices, and identify the tradeoffs involved in this change.

Significant research should also be directed to understanding what incentives, payment schemes, laws, policies or socioeconomic conditions provide the appropriate stimuli and conditions for farmer adoption (and continued use) of environmentally sustainable management strategies. While some research has been directed towards understanding how, when and why farmers adopt agroforestry systems in the region (e.g. Scherr and Current, 1995), comparable studies on the adoption of organic production systems, integrated pest management and other proposed mitigation strategies are lacking. If this information were available, it would be easier to tailor policies, incentives, extension services and training to meet the particular needs of local communities and to highlight issues that are most relevant to a particular location or situation.

Finally, it is important to have access to current information on relationships between regulations, institutional factors, market factors and agriculture. The social and economic forces affecting agriculture are highly dynamic and site-specific, making it critical that these relationships be examined in the appropriate spatial and temporal context. Relationships which occurred in the past may vanish or lose strength in the course of months due to fluctuations in international markets or the adoption of new free trade agreements, and become more or less relevant as explanations of land use patterns. Consequently, access to up-to-date and site-specific information is key for successful mitigation efforts.

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Appendix 1. Summary of the literature (a) and webpages (b) consulted.

a) Literature

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b) Web sites

Site	Link
1. CABI commodities	http://www.cabi-commodities.org/Acc/ACCrc/ACCrcCOCb.p.htm
2. Center for International Forestry Research	http://www.cifor.cgiar.org/dbtw-wpd/exec/dbtwpub.dll
3. Center for International Forestry Research (CIFOR)	http://www.cifor.cgiar.org/fire-project/index.htm
4. Centre for research on sustainable agricultural production systems (CIPAV)	http://www.cipav.org.co/

5. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)	www.catie.ac.cr
6. Coalición Internacional para el Acceso a la Tierra	http://www.landcoalition.org/
7. Comisión Centroamericana de Ambiente y Desarrollo (CCAD)	http://www.ccad.ws/
8. Comisión económica para América Latina y el Caribe (CEPAL)	http://www.eclac.cl
9. Comisión para la Cooperación Ambiental en América del Norte (CEC)	http://www.cec.org/
10. Consejo Regional de Cooperación Agrícola (CORECA)	http://www.coreca.org/
11. Conservation International (CI)	www.conservation.org
12. Convention on biological diversity	http://www.biodiv.org/default.aspx
13. Convention on Biological Diversity	http://www.biodiv.org/default.aspx
14. Coordinadora Latinoamericana de Organizaciones de Campo	http://movimientos.org/
15. Corredor Biológico Mesoamericano	www.biomeso.net
16. Earth Trends	http://earthtrends.wri.org
17. Earthwatch	www.earthwatch.org
18. Environmental Working Group	http://www.ewg.org/
19. Estado de la Biodiversidad en Costa Rica	http://www.minae.go.cr/estrategia/Estudio_Pais/estudio/Paginas/frame_estudio.htm
20. Estado de la Región	www.estadonacion.or.cr
21. FAOSTAT	http://faostat.fao.org/default.jsp
22. Fondo Nacional de Financiamiento Forestal de Costa Rica (FONAFIFO)	http://www.fonafifo.com
23. Food and agriculture organization (FAO)	www.fao.org
24. Global Environmental Facility (GEF)	http://www.gefweb.org/
25. Global Fire Monitoring Center	http://www.fire.uni-freiburg.de/
26. International Food Policy Research Institute (IFPRI)	http://www.ifpri.org/pubs/pubs.htm
27. International Institute of Tropical Agriculture (IITA)	http://www.iita.org/info/info.htm
28. International Network for the Improvement of Banana and Plantain (INIBAP)	http://www.inibap.org
29. Instituto Australiano de Ciencias Marinas.	http://www.aims.gov.au/
30. Instituto de Café (ICAFE)	www.icafe.go.cr
31. Instituto Interamericano de Cooperación para la Agricultura (IICA)	http://www.iica.int/
32. Instituto Nacional de Biodiversidad (INBio)	www.inbio.ac.cr
33. Inter.-American Development Bank (IDB)	http://www.iadb.org/
34. Inter-American Institute for Cooperation	www.iica.int

on Agriculture (IICA)	
35. International Association for Impact Assessment	http://www.iaia.org/
36. International Coffee Organization	http://www.ico.org/
37. International Rice Research Institute (IRRI)	http://www.irri.org/publications/catalog/index.asp
38. IUCN- Humedales	http://www.uicnhumedales.org/enlinea.htm
39. IUCN Red lists	www.Redlist.org
40. Livestock, environment and development (LEAD) virtual research and development centre	http://www.lead.virtualcentre.org/selector.htm
41. Mesoamerican barrier reef project.	http://www.mbrs.org.bz/
42. Metabase	http://www.metabase.net/
43. Organization for Economic Co-operation and Development	http://www.oecd.org/home
44. Pesticide information data base	http://www.pesticideinfo.org/Index.html
45. Programa Cooperativo Regional para el Desarrollo Tecnológico y la Modernización de la Caficultura de Centroamérica, República Dominicana y Jamaica (PROMECAFE)	http://www.iica.int/foragro/promecafe.asp
46. Programa Salvadoreño de investigación sobre desarrollo y medio ambiente (PRISMA)	http://www.prisma.org.sv/pubs/csa_es_en.htm
47. Red de Evaluación del Impacto Ambiental	http://www.eia-centroamerica.org/centro_documental
48. Secretaría de Integración Económica Centroamericana (SIECA)	http://www.sieca.org.gt/
49. Sistema Nacional de Áreas Protegidas, Costa Rica	http://www.sinac.go.cr
50. Smithsonian Migratory Bird Center	http://nationalzoo.si.edu/ConservationAndScience/MigratoryBirds
51. The International Centre for Tropical Agriculture (CIAT)	http://www.ciat.cgiar.org
52. The Nature Conservancy	www.tnc.org
53. The Rain Forest Alliance	http://www.rainforestalliance.org/
54. The World Bank	http://www.worldbank.org/
55. The World Conservation Union IUCN	http://www.iucn.org/places/orma/
56. Unidad Regional de Asistencia Técnica en Centroamerica (RUTA)	http://www.ruta.org/index.shtml
57. United National Environment Program (UNEP)	http://www.undp.org
58. United Nations Educational, Scientific and Cultural Organization (UNESCO)	http://www.unesco.org/mab/br/focus/2002Sep/Bosawas.htm
59. Universidad Nacional library	www.una.ac.cr
60. Universty of Idaho	www.lib.uidaho.edu
61. Wetlands International	http://www.wetlands.org/

62. World Wildlife Fund (WWF)	http://worldwildlife.org/science/ecoregions.cfm
63. World Agroforestry Center	http://www.worldagroforestrycentre.org/home.asp
64. World Conservation Monitoring Centre	http://www.unep-wcmc.org/protected_areas/
65. World Rainforest Movement	http://www.wrm.org/
66. World Resource Institute	www.wri.org
67. World Watch	www.worldwatch.org

Appendix 2. List of experts who provided information for the report.

Number	Name	Institution
1	Andraka Sandra	World Wildlife Fund (WWF)
3	Argumedo Gladis	Secretaría General del Sistema de la Integración Centroamericana (SG-SICA)
4	Bach Oliver	Universidad Nacional de Educación a Distancia (UNED)
5	Barona A.Elizabeth	Centro Internacional de Agricultura Tropical (CIAT)
6	Beer John	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)
7	Benjamin Tamara	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)
8	Boshier David	Oxford Forestry Institute (OFI)
9	Brenes Oscar	Formerly of WWF
10	Burke Lauretta	World Resources Institute
11	Carazo Felipe	The Nature Conservancy (TNC)
12	Carrera Gambetta Fernando	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)
13	Carrillo Eduardo	Programa regional en manejo de vida silvestre para Mesoamerica de la Universidad Nacional de Costa Rica (PRMVS, UNA)
14	Carrillo Eduardo	UNA, Wildlife Conservation Society
15	Castro Marco	The Nature Conservancy (TNC)
16	Corales Ana Lucia	Rain Forest Alliance
17	Edwards Melissa	Freshwater Program Officer WWF-Central America Regional Office
18	Evans Pascale	International Coffee Organization
19	Ewel Jack	University of Florida
20	Fergusen Bruce	El colegio de la frontera sur (ECOSUR)
21	Finegan Bryan	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)
22	Flores Juan Carlos	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)
23	Galloway Glenn	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)
24	García Jaime	Universidad Nacional de Educación a Distancia (UNED)
25	García O. Luis Alberto	Centro Internacional de Agricultura Tropical (CIAT)
26	Gomez Rene	Nitlapán
27	Grham Glenn	Centro Internacional de Agricultura Tropical (CIAT)
28	Harrison Michele	World Resources Institute
29	Hilje Luko	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)
30	Jiménez Francisco	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)
31	Kapelle Maarten	The Nature Conservancy (TNC)
32	Kleinn Christoph	University of Göttingen, Germany
33	Lahmann Enrique J.	The World Conservation Union (IUCN) - Mesoamerica
34	Marchamo Miguel	Universidad de Costa Rica (UCR)
35	McNeely Jeffrey	The World Conservation Union (IUCN)
36	Monterroso Ottoniel	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)

37	Mora Jairo	Livestock, Environment and Development Initiative (LEAD) Virtual Centre
38	Morales Helda	El Colegio del Sur (ECOSUR)
39	Murgueito Enrique	Fundación CIPAV (Centro para la Investigación en Sistemas Sostenibles de Producción Agropecuaria)
40	Pimentel David	Cornell University
41	Pocasangre Luis	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)
42	Power Alison	Cornell University
43	Ramírez Jeannette F	Instituto Costarricense del Café (ICAFE)
44	Ramos de Rivera Otty	Comisión Centroamericana de Ambiente y Desarrollo (CCAD)
45	Rivera Maritza	The World Conservation Union (IUCN) -Mesoamerica
46	Rusillo Aimee	Rain Forest Alliance
47	Sabarniati Nia	Center for International Forestry Research (CIFOR)
48	Sabido Wilber	Programme for Belize
49	Sáenz Joel	Programa regional en manejo de vida silvestre para Mesoamerica de la Universidad Nacional de Costa Rica (PRMVS, UNA)
50	Sánchez Dalia	Fundación Cocibolca, Nicaragua
51	Secaira Estuardo	The Nature Conservancy (TNC)
52	Vaast Philippe	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)
53	Vandermeer John	University of Michigan
54	Vanegas Guillermo	Comisión Centroamericana de Ambiente y Desarrollo (CCAD)
55	Villegas Florangel	The World Conservation Union (IUCN)
56	Walsh Bryon	Ministerio de Ambiente y Recursos Naturales, Nicaragua
57	Warner Carola	Invasive Species Specialist Group/IUCN

Appendix 3. Modified hierarchical classification scheme of the major terrestrial ecosystem types, major terrestrial habitat types and terrestrial ecoregions of Central America (based on Dinerstein *et al.*, 1995).

Major ecosystem type	Major habitat type	Ecoregion	Characteristics*	Biological Distinctiveness	Conservation Status
TROPICAL BROADLEAF FOREST	Tropical Moist Broadleaf Forest	1. Tehuantepec moist forest	Countries: Mexico, Guatemala, Belize Area: 146,752 km ²	Bioregionally outstanding	Endangered
		2. Sierra Madre moist forest	Countries: México, Guatemala, El Salvador Area: 9,137 km ²	Bioregionally outstanding	Endangered
		3. Central American montane forests	Countries: Mexico, Guatemala, El Salvador, Honduras Area: 13,300 km ²	Bioregionally outstanding	Endangered
		4. Belizean swamp forests	Country: Belize Area: 4,150 km ²	Locally important	Endangered
		5. Central American Atlantic moist forests	Countries: Guatemala, Belize, Honduras, Nicaragua, Costa Rica, Panamá Area: 89,500 km ²	Bioregionally outstanding	Vulnerable
		6. Costa Rican seasonal moist forests	Country: Costa Rica, Nicaragua Area: 10,700 km ²	Locally important	Critical
		7. Isthmian-Pacific moist forests	Country: Costa Rica, Panamá Area: 29,300 km ²	Bioregionally outstanding	Critical/ endangered
		8. Talamancan montane forests	Countries: Costa Rica, Panamá Area: 16,300 km ²	Regionally outstanding	Relatively stable

Major ecosystem type	Major habitat type	Ecoregion	Characteristics*	Biological Distinctiveness	Conservation Status
	Tropical Dry Broadleaf Forest	9. Central American Pacific dry forests	Countries: El Salvador, Honduras, Nicaragua, Costa Rica, Guatemala Area: 68,000 km ²	Bioregionally outstanding	Critical
		10. Panamanian dry forests	Country: Panama Area: 5,100 km ²	Locally important	Critical
CONIFER/ TEMPERATE BROADLEAF FORESTS	Tropical and Subtropical Coniferous Forests	11. Central American pine-oak forests	Countries: México, Guatemala, El Salvador, Honduras, Nicaragua Area: 111,400 km ²	Bioregionally outstanding	Vulnerable
		12. Belizean pine forest	Country: Belize Area: 2,800 km ²	Regionally outstanding	Relatively stable
		13. Miskito Pine Forest	Countries: Nicaragua, Honduras Area: 18,900 km ²	Regionally outstanding	Relatively stable
GRASSLANDS/ SAVANNAS/ SHRUBLANDS	Montane Grasslands	14. Costa Rican paramo	Country: Costa Rica. Area: 31 km ²	Bioregionally outstanding	Relatively stable
XERIC FORMATIONS	Deserts and Xeric scrublands	15. Motagua Valley thornscrub	Country: Guatemala Area: 2,363 km ²	Bioregionally outstanding	Critical/endangered
MANGROVES	Atlantic Mangrove Complexes and Mangrove units (Atlantic Central America)	16. Northern Honduras	Country: Honduras Area: 1,100 km ²	N/a	Vulnerable

Major ecosystem type	Major habitat type	Ecoregion	Characteristics*	Biological Distinctiveness	Conservation Status
		17. Mosquitia/ Nicaraguan Caribbean Coast	Countries: Honduras, Nicaragua Area: 4,400 km ²	N/a	Relatively stable
		18. Río Negro/ Río San Juan	Countries: Nicaragua, Costa Rica Area: 500 km ²	N/a	Critical/ endangered
		19. Bocas del Toro/Bastimentos Island/San Blas	Country: Panama Area: 500 km ²	N/a	Vulnerable
	Pacific Mangrove Complexes and Mangrove units (Pacific Central America)	20. Tehuantepec/ El Manchón	Country: Mexico, Guatemala Area: 2,900 km ²	N/a	Relatively stable
		21. Northern Dry Pacific Coast	Country: Guatemala, El Salvador Area: 1,100 km ²	critical/endangered	N/a
		22. Gulf of Fonseca	Countries: El Salvador, Honduras, Nicaragua Area: 1,600 km ²	N/a	Critical/endangered
		23. Southern Dry Pacific Coast	Countries: Costa Rica Area: 900 km ²	N/a	Critical
		24. Moist Pacific Coast	Countries: Costa Rica Area: 1,600 km ²	N/a	Vulnerable
		25. Panama Dry Pacific Coast	Country: Panama	N/a	Relatively stable

Source: Dinerstein et al. (1995). *Area from WWF (2003) <http://worldwildlife.org/science/ecoregions/biomes.cfm>

Appendix 4. A preliminary overview of the known types of agriculture and the main threats of agricultural systems to the 26 ecoregions in Central America (based on Dinerstein *et al.* 1995 and information from experts). Because specific information on individual ecoregions is very limited, these data should be interpreted with much caution. It is likely that many (if not most) of these ecoregions contain more agricultural systems and face more threats from agriculture than reported here, however this information is not available.

Ecoregion	Agricultural crops present in ecoregion									Specific threats related to agriculture in each ecoregion										
	1.1. General agricultural expansion	Banana	Cattle	Sugarcane	Coffee production	Small scale agriculture/ subsistence agriculture	Pineapple	Oil palm	Other crops	Sedimentation of streams	Extraction of firewood	Hydrological changes (streams, etc.)	Pesticide use/agrochemical runoff	Logging	Fire/burning	Soil erosion	Squatting/invasion of lands	Hunting	Road building	
Techauntepec moist forest	X	X	X			X			X*											X
Sierra Madre moist forest	X				X					X			X							
CA montane forests	X		X	X	X	X				X	X				X	X				
Belizean swamp forest	X									X								X	X	
Central American Atlantic moist forests	X	X	X			X	X	X	X		X		X	X	X					

Costa Rican seasonal moist forests	X		X	X										X				
Isthmian Pacific moist forests	X	X	X										X	X		X	X	
Talamancan montane forests	X		X		X								X	X	X	X		
Central American Pacific dry forests	X		X			X				X	X			X	X		X	
Panamanian dry forests	X		X			X								X			X	
Central American pine-oak forests	X		X		X	X			X		X	X	X	X	X			X
Belizian pine forest		X							X *				X	X				
Miskito pine forest										X			X	X				
Costa Rican paramo														X				
Motagua Valley thornscrub			X **											X				
Northern Honduras	X		X			X			X	X		X		X	X		X	
Mosquitia Nicaraguan Caribbean Coast	X		X			X			X		X	X	X	X	X	X	X	
Rio Negro/Rio San Sun		X						X	X			X			X		X	
Bocas del Toro/Bastimentos Island/San Blas						X												
Tehuantepec/ E.I. Manchon)	X										X	X	X				X	X
Northern Dry Pacific Coast	X		X	X					X		X	X		X	X			
Golf of Fonseca						X			X	X				X	X	X		

Southern Dry Pacific Coast			X			X				X	X			X	X	X			
Moist Pacific Coast	X		X			X				X	X		X	X		X			
Panama Dry Pacific Coast*			X			X													
Total	16	5	15	3	4	13	1	2	3	8	9	6	7	11	16	12	5	8	4

* Citrus

** Goats

Appendix 5. Summary of the total amount of area (in hectares x 1000 and %) dedicated to the production of agricultural crops and pastures in Central America. Data for agricultural crops are from 2003; data for pastures are from 2001.

Agricultural system	Belize		Costa Rica		El Salvador		Guatemala		Honduras		Nicaragua		Panama	
	(x 1000 ha)	%	(x 1000 ha)	%	(x 1000 ha)	%	(x 1000 ha)	%	(x 1000 ha)	%	(x 1000 ha)	%	(x 1000 ha)	%
Banana	1.94	0.08	45.00	0.88	6.00	0.29	19.04	0.18	23.00	0.21	1.00	0.01	13.50	0.18
Cocoa	0.09	0.00	3.55	0.07	0.05	0.00	4.06	0.04	4.80	0.04	2.00	0.02	4.50	0.06
Coffee	0.04	0.00	95.00	1.86	160.95	7.65	245.00	2.34	215.00	1.92	115.73	0.95	23.50	0.32
Sugarcane	24.50	1.07	48.00	0.94	58.87	2.80	186.34	1.78	49.00	0.44	41.98	0.35	35.00	0.47
Cereals*	23.5	1.03	67	1.31	328.73	15.62	666.45	6.36	404.99	3.62	508.102	4.19	117	0.40
African oil palm	n.d.	n.d.	38.00	0.74	n.d.	n.d.	19.10	0.18	45.00	0.02	2.00	0.02	n.d.	n.d.
Vegetables and melons	1.02	0.04	16.47	0.32	9.22	0.44	59.23	0.57	20.82	0.19	12.66	0.10	20.57	0.28
Roots and tubers**	0.52	0.02	17.35	0.34	5.14	0.24	15.50	0.15	4.61	0.04	8.50	0.07	8.55	0.11
Total area under crops	57.24	2.51	390.37	7.65	574.25	27.29	1229.22	11.73	770.71	6.89	782.22	6.44	307.62	4.13
Pastures	50	2.2	2,340	45.8	794	37.7	2,602	24.8	1,508	13.5	n.a	n.a.	n.a.	n.a.
Total country area	2,280		5,106		2,104		10,483		11,189		12,140		7,443	

Source: FAOSTAT 2004. * includes wheat, maize, rice, barley, rye , oats, birdseed , millet and others

** includes potatoes, sweet potatoes, yucca, yam, **malanga**

Appendix 6. Summary of the total value of fungicides (a), insecticides (b) and herbicides (c) imported by Central American countries, from 1990 to 2002. Data are based on FAOSTAT 2004 (<http://faostat.fao.org/default.jsp>., consulted March 2004). Missing data are indicated by ‘-’.

a) Fungicides

Value imports (1000\$)	Year												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Belice	856	-	1,007	1,522	1,387	1,142	1,521	1,535	1,084	-	1,040	-	-
Costa Rica	15,248	25,142	22,079	21,772	34,156	41,149	36,807	48,335	51,733	48,161	39,333	38,460	44,348
El Salvador	2,650	1,011	903	724	1,208	1,529	1,471	1,377	1,957	1,361	2,210	1,525	1,268
Guatemala	-	-	16,188	10,381	12,050	17,503	15,584	16,721	16,796	15,359	15,558	14,518	14,607
Honduras	7,943	11,702	13,436	22,379	17,350	18,678	18,233	16,707	10,960	9,046	8,436	-	11,789
México	15,935	24,224	31,959	33,906	44,524	36,471	45,374	55,947	56,764	63,292	57,567	55,330	60,296
Nicaragua	1,235	1,301	645	1,988	3,059	4,632	4,377	4,944	7,005	7,735	7,488	6,212	5,444
Panama	-	-	-	23,686	-	-	14,571	14,583	11,282	12,484	10,942	7,571	-

b) Herbicides

Value imports (1000\$)	Year												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Belize	836	-	1,025	1,173	1,587	1,403	1,784	1,742	1,537	-	2,363	-	-
Costa Rica	12,208	9,666	12,177	9,757	16,416	16,688	16,474	17,034	17,878	16,918	19,202	19,052	20,232
El Salvador	45	2,116	4,407	3,960	4,567	7,531	8,637	7,153	7,042	8,719	11,754	14,213	13,650
Guatemala	-	-	10,870	13,057	14,863	17,483	17,902	17,062	17,833	14,348	14,955	15,742	19,233
Honduras	6,644	7,395	5,034	8,022	8,220	8,668	11,062	10,431	11,261	13,696	12,922	-	16,585
Nicaragua	1,874	3,484	2,874	5,918	6,963	7,974	7,075	9,175	10,659	11,672	8,821	7,990	9,502
Panama	-	-	-	4,465	-	-	15,205	12,623	11,090	15,419	15,280	14,654	12,999

c) Insecticides

Value of imports (1000 \$)	Year												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Belize	1,715	-	1,634	1,626	1,899	1,917	2,412	2,244	2,080	-	3,078	-	-
Costa Rica	11,262	11,801	8,506	9,606	12,496	16,996	15,787	17,490	24,034	21,753	19,662	20,696	20,316
El Salvador	463	4,885	5,781	5,241	7,900	7,837	6,117	8,559	8,507	9,154	10,260	10,186	10,890
Guatemala	-	-	21,118	12,524	12,203	13,084	12,582	13,087	16,142	13,465	14,256	23,155	19,412
Honduras	6,115	6,823	4,072	7,553	5,849	6,828	9,538	2,262	6,992	9,496	8,667	-	11,584
Nicaragua	13,712	12,356	3,772	3,953	4,142	6,058	5,607	6,314	8,825	7,892	6,051	5,260	8,703
Panama	-	-	159	-	-	-	5,578	6,669	7,034	6,415	6,832	6,604	-

Appendix 7. Possible effects of CAFTA on Central American agriculture and biodiversity conservation.

In January 2004, the Central American countries of Guatemala, Honduras, El Salvador, Nicaragua and Costa Rica, and the United States of America signed the Central American Free Trade Agreement (CAFTA). This agreement is a key element of USA's policy towards Central America and, if ratified by the respective congresses and parliaments of each country, is likely to have a significant impact not on only trade, but also the overall development of the region.

In order to fully understand the potential impact of CAFTA on Central American agriculture and biodiversity, we need to consider three important issues. The first one is the role of agriculture in the region. As we have discussed earlier, agricultural exports constitute an important share of total exports in all Central American countries and a key source of employment. As countries find ways to add value to the production of agricultural and forest products through the opportunities that arise from CAFTA, it is likely that the primary sector will increase in importance. Since agricultural production is heavily dependent on the availability of natural resources and land is now scarce, any increases in agricultural production are likely to put additional pressure on the environment and agricultural land.

The second issue is the fact that international agricultural markets have been undergoing a profound restructuring process that is largely independent of efforts towards trade liberalization. The restructuring includes changes in product demand, changes in production methods and changes in transport related costs, and all three factors are likely to exert an impact on biodiversity inasmuch as they impact the flow of agricultural products. For example, changes in demand for agricultural products, due to varying consumption patterns and increased incomes, can have either positive or negative effects on biodiversity conservation. On the one hand, increases in the consumption of meat and heavily processed food can stimulate the expansion of large-scale single crop plantations and livestock farms which may lead to increased deforestation and/or agricultural intensification (UNEP, 1999, Cranfield, 1998). On the other hand, consumers in higher income countries are showing increasing interest for food that is produced with low impact agricultural practices (such as organic agriculture) or that is free of genetically modified organisms (CEC, 2000), and these demands may stimulate the adoption of more environmentally friendly production systems (with a positive impact on biodiversity).

Another important change in agricultural markets is the shift towards larger scale, modern agriculture, with high agrochemical inputs, which can have important consequences for biodiversity conservation. Countries are now becoming more specialized in their exports and rely more on a narrow range of plant genetic material, and this may have mixed consequences for biodiversity. Newer technologies and new varieties may be more productive (and require less land), but could result in the loss of agrobiodiversity and place added pressure on the remaining natural habitats. Finally, transportation costs have been steadily on the decline due to lower maritime fares and better access to remote new locations. This ability to easily transport products over larger distances and to a greater number of new places is potentially very dangerous for biodiversity, given the associated risk of increased species invasions.

The third important consideration is that although Central American agriculture is already strongly affected by a number of organizations (such as GATT and the World Trade Organization) and existing trade agreements (for example the Agreement on Subsidies and Compensatory Measures and the

Agreement on Agriculture of the WTO), and is already integrated into the global market (as shown by the increasing flow of goods traded between Central America and the rest of the world, Table 1), the ratification of CAFTA may change the way in which these agreements work. Although there is no discussion table specifically working on environmental issues related to these agreements at the international level (i.e. WTO), the existing agreements generally accept the principle that each country is responsible for the protection and conservation of its own environment and its natural resources, and has the right to determine the level of environmental quality it prefers. There are two important consequences of this principle: 1) if the production or disposal of an exportable good can potentially create environmental damage in the importing country, then this country can impose a barrier to the import of this good, and 2) if the production of an exportable good can potentially create an environmental damage in the exporting country, then the importing country cannot impose obstacles to imports of this particular good (Pomareda, 2002). However, some developed countries (including the USA) do not agree with this principle because they believe that if customers in their local markets demand high environmental standards from local producers, they should be allowed to do the same with similar imported goods. In addition, producers in developed countries fear competition due to lax environmental standards and regulations in exporting countries, and the lack of funds and monitoring capacity to enforce those regulations.

Table 1. Trade balance and degree of openness of Central America (millions of US\$).

Year	Exports	Imports	Trade Balance	GDP	Index of Trade Openness
1990	3,922	6,320	-2,398	22,446	0.45
2000	11,476	18,906	-7,430	56,096	0.54

Source: Pomareda (2003)

Although CAFTA is bound by the general principle that each country is responsible for its own environment (and subject to its own environmental laws), it adds a new twist to these laws which ultimately allows the USA to fine a country if its exporters are competing based on unsustainable exploitation of natural resources in the exporting country. According to CAFTA, exporters in each country must comply with all their own local environmental regulations, or else the country, as a whole is liable to a fine. Given that Central American countries have fairly advanced environmental laws (in line with international, developed country standards) but lack the capacity and funds to enforce these laws, this means that the USA is now able to fine a country if its exporters are failing to comply with the country's environmental legislation. From an environmental perspective, the effect of this new law is expected to be positive in the short run, as governments ensure that exporters comply with existing environmental regulations. In the long run, however, governments are expected to be much more cautious in passing strict environmental regulation for fear that these regulations may hurt the export sector or result in fines by the USA.

Another, more direct way, in which CAFTA may affect agriculture in Central America (and thereby indirectly affect the environment) is by influencing which agricultural products are grown in the region. As a result of CAFTA, it is likely that some agricultural products will be phased out in favor of new ones

as the economies of individual countries adjust to the flow of imported goods from the rest of the countries in Central America and the USA and to new market niches in those countries. In the past, subsidies and protective measures have led to inefficiencies in domestic agricultural markets and the playing field is full of complex mixes of high tariff and non-tariff protective measures coupled with export subsidies and controlled local price schemes. Although CAFTA is not likely to eliminate all these measures and correct for all of these distortions, it is likely that increased competition will force some non-competitive producers out of the market while promoting other, more efficient, producers to look for new markets. Furthermore, we could also expect a shift in the pattern of trade, with USA seeing a decrease in agricultural exports and a focus on more value-added products, and Central America, conversely, seeing an expansion in agricultural exports. The most significant biodiversity-related impacts resulting from this pattern of changes centers on the question of land use change.

It is important to note that the relationship between agricultural production and biodiversity will be case and site specific. In order to clearly establish the potential impact of CAFTA on biodiversity in a given country, it will be necessary to determine which current distortions will be eliminated or exacerbated, how these new conditions affect the prices of different agricultural crops, and which agricultural sectors will increase whereas another will decrease as a result of these changes. As different agricultural crops have distinct effects on biodiversity (due to differences in their use of agrochemicals, demand for new land, etc.), the net effect on biodiversity will depend on whether the changes in crops and production systems result in additional deforestation and intensification via increased agrochemical use, or in the adoption of more environmentally friendly systems and landscapes. For example, in the case of Costa Rica, experts agree that the adoption of CAFTA will favor sugar cane due to increased access to the US market; but negatively affect the production of rice (which is currently heavily subsidized) due to tough competition from imported grains. Since both products can be planted in the same areas, one could expect a marked shift from rice to sugar cane production in these areas, which could potentially be beneficial to biodiversity as sugarcane requires less agrochemicals and is less water demanding than rice.

In summary, the ratification of CAFTA is expected to create markets for some Central American agricultural products, destroy markets for others, and result in an overall increase in the flow of agricultural products from Central American countries to the USA. In addition, the adoption of the new laws (within CAFTA) that require exporters to comply with local environmental regulations or else subject the host country to fines, is expected to improve environmental conditions in the short run, but might prevent the development of new, more advanced, environmental regulations in the future. The cumulative effect on agriculture and biodiversity is largely unknown and will likely vary greatly from site to site.

Appendix 8. List of known invasive species in Central America, by country.

Country	Invasive species		
	Alien	Native	Biostatus Uncertain
Belize	<i>Ziziphus mauritiana</i> (shrub, tree)	<i>Acacia farnesiana</i> (shrub, tree)	<i>Cedrela odorata</i> (shrub, tree)
		<i>Bufo marinus</i> (amphibian)	
		<i>Leucaena leucocephala</i> (tree)	
		<i>Miconia calvescens</i> (tree)	
		<i>Psidium guajava</i> (shrub, tree)	
		<i>Solanum tampicense</i> (shrub)	
		<i>Solenopsis geminata</i> (ant, insect)	
Costa Rica	<i>Casuarina equisetifolia</i> (tree)	<i>Acacia farnesiana</i> (shrub, tree)	<i>Cedrela odorata</i> (shrub, tree)
	<i>Cyprinus carpio</i> (fish)	<i>Bufo marinus</i> (amphibian)	<i>Psidium guajava</i> (shrub, tree)
	<i>Eichhornia crassipes</i> (aquatic plant)	<i>Chromolaena odorata</i> (herb)	<i>Urochloa maxima</i> (grass)
	<i>Herpestes javanicus</i> (mammal)	<i>Cinchona pubescens</i> (tree)	
	<i>Leucaena leucocephala</i> (tree)	<i>Miconia calvescens</i> (tree)	
	<i>Micropterus salmoides</i> (fish)	<i>Psidium guajava</i> (shrub, tree)	
	<i>Oreochromis mossambicus</i> (fish)	<i>Solanum tampicense</i> (shrub)	
	<i>Pennisetum clandestinum</i> (grass)	<i>Solenopsis geminata</i> (ant, insect)	
	<i>Trachemys scripta elegans</i> (reptile)	<i>Wasmannia auropunctata</i> (ant, insect)	
El Salvador	<i>Cyprinus carpio</i> (fish)	<i>Acacia farnesiana</i> (shrub, tree)	<i>Cedrela odorata</i> (shrub, tree)
	<i>Leucaena leucocephala</i> (tree)	<i>Bufo marinus</i> (amphibian)	<i>Psidium guajava</i> (shrub, tree)
	<i>Micropterus salmoides</i> (fish)	<i>Chromolaena odorata</i> (herb)	
	<i>Oreochromis mossambicus</i> (fish)	<i>Psidium guajava</i> (shrub, tree)	
		<i>Solanum tampicense</i> (shrub)	
Guatemala	<i>Cyprinus carpio</i> (fish)	<i>Acacia farnesiana</i> (shrub, tree)	<i>Cedrela odorata</i> (shrub, tree)
	<i>Eichhornia crassipes</i> (aquatic plant)	<i>Bufo marinus</i> (amphibian)	<i>Piper aduncum</i> (shrub, tree)
	<i>Leucaena leucocephala</i> (tree)	<i>Chromolaena odorata</i> (herb)	
	<i>Micropterus salmoides</i> (fish)	<i>Miconia calvescens</i> (tree)	
	<i>Oreochromis mossambicus</i> (fish)	<i>Psidium guajava</i> (shrub, tree)	
	<i>Ziziphus mauritiana</i> (shrub, tree)	<i>Solanum tampicense</i> (shrub)	
		<i>Solenopsis geminata</i> (ant, insect)	
		<i>Wasmannia auropunctata</i> (ant)	
Honduras	<i>Cyprinus carpio</i> (fish)	<i>Acacia farnesiana</i> (shrub, tree)	<i>Cedrela odorata</i> (shrub, tree)
	<i>Eichhornia crassipes</i> (aquatic plant)	<i>Bufo marinus</i> (amphibian)	
	<i>Herpestes javanicus</i> (mammal)	<i>Chromolaena odorata</i> (herb)	

	<u>Homalodisca coagulata</u> (insect)	<u>Psidium guajava</u> (shrub, tree)	
	<u>Leucaena leucocephala</u> (tree)	<u>Solanum viarum</u> (shrub)	
	<u>Micropterus salmoides</u> (fish)	<u>Solenopsis geminata</u> (ant, insect)	
	<u>Oreochromis mossambicus</u> (fish)	<u>Wasmannia auropunctata</u> (ant, insect)	
	<u>Psidium guajava</u> (shrub, tree)		
Nicaragua	<u>Cyprinus carpio</u> (fish)	<u>Acacia farnesiana</u> (shrub, tree)	<u>Cedrela odorata</u> (shrub, tree)
	<u>Eichhornia crassipes</u> (aquatic plant)	<u>Bufo marinus</u> (amphibian)	
	<u>Oreochromis mossambicus</u> (fish)	<u>Chromolaena odorata</u> (herb)	
		<u>Psidium guajava</u> (shrub, tree)	
		<u>Solenopsis geminata</u> (ant, insect)	
		<u>Wasmannia auropunctata</u> (ant, insect)	
Panama	<u>Cyprinus carpio</u> (fish)	<u>Acacia farnesiana</u> (shrub, tree)	<u>Cedrela odorata</u> (shrub, tree)
	<u>Eichhornia crassipes</u> (aquatic plant)	<u>Bufo marinus</u> (amphibian)	
	<u>Herpestes javanicus</u> (mammal)	<u>Chromolaena odorata</u> (herb)	
	<u>Leucaena leucocephala</u> (tree)	<u>Cinchona pubescens</u> (tree)	
	<u>Micropterus salmoides</u> (fish)	<u>Psidium guajava</u> (shrub, tree)	
	<u>Oreochromis mossambicus</u> (fish)	<u>Solenopsis geminata</u> (ant, insect)	
	<u>Piper aduncum</u> (shrub, tree)	<u>Wasmannia auropunctata</u> (ant, insect)	
	<u>Salmo trutta</u> (fish)		

Source: Invasive Species Specialist Group, IUCN (2004)

Appendix 9. Number of wildfires (including those initiated both by natural process and agriculture) in Central America from 1996 to 2001.

Country	Fire number by year						
	1996	1997	1998	1999	2000	2001	Total
Belize	138	651	611	683	404	715	3,202
Costa Rica	490	673	882	267	371	818	3,501
El Salvador	124	390	207	158	466	1,169	2,514
Guatemala	695	5,027	7,943	5,520	6,049	3,143	28,377
Honduras	1,430	7,376	6,983	3,306	4,567	4,797	28,459
Nicaragua	4,183	8,256	7,877	2,505	4,922	4,731	32,474
Panamá	513	399	2,974	563	522	1,408	6,379
Central America	7,573	22,772	27,477	13,002	17,301	16,781	104,906

Source: Laforge (2001)

Appendix 10. Summary of main effects of the four principal agricultural systems (coffee, cattle production, banana and sugarcane) on biodiversity in Central America

Coffee

Coffee production is one of the most important agricultural activities in Central America, covering an estimated 831,000 ha (FAOSTAT, 2004) and accounting for 8.4% of the region's exports to the Common Central American Market³. In addition, coffee is one of the main sources of agricultural employment, with Nicaragua having an estimated 30,4000 coffee producers (90% of which are small and medium farmers,; UNICAFE coffee atlas) By virtue of the vast area over which it extends and the fact that many of the coffee regions overlap with priority areas for conservation that have high richness or endemism (Somarriba *et al.*, 2004), the effects of coffee plantations on biodiversity are of critical importance to conservation efforts in the region. Activities that could lessen the negative impacts of coffee production or promote biodiversity conservation within these systems could therefore have an important impact on conservation efforts at both national, regional and supraregional scales (Somarriba *et al.*, 2004).

In Central America, coffee is grown under a variety of different management systems, ranging from open sun plantations (which lack a shade tree component and typically have high levels of fertilizers, herbicides and pesticide inputs), to diverse and densely shaded agroforestry systems with minimal input of agrochemicals. Somarriba and colleagues (2004) recognize five main types of coffee plantations: 1) coffee grown under full sun (no shade), 2) coffee with monolayered shade canopies (usually of *Erythrina* or *Inga* species); 3) two-layered shade canopies; 4) multistory coffee plantations with 3 or more tree species and three or more vertical strata; and 5) rustic coffee plantations where the natural forest understory is cleared to plant coffee bushes, and the forest canopy is thinned and enriched by planting useful plants. Differences across coffee production systems stem from differences in climatic conditions, soil conditions, and socioeconomic factors, as well as historic differences. The design and management of the shade component of coffee systems depends on local climatic conditions, tradeoffs between coffee yields and plantation longevity, and plantation size and the need for diversification. Whereas regions that are hot and dry, or very windy (such as the lowlands in El Salvador), require tree shade for coffee production, areas that are cool, humid or cloudy (e.g. the highlands of Costa Rica where it rains 2,500 to 3,500 mm per year) make shade unnecessary. Another factor that influences the use of shade is the tradeoff between plantation longevity and coffee yields: coffee plantations with little or no shade and high agrochemical inputs can achieve high yields but these plantations must be renovated more frequently (every 12-15 yrs) compared to shaded plantations (which have lower yields but higher longevity, requiring renovation every 15-20 years). Important differences also occur across farms of different sizes, with large farms specialized in coffee generally using simple shade canopies of one or two species, that are regularly planted, pollarded and thinned, and with small farmers choosing diversified polycultural systems including fruit, timber and firewood species that provide important products for farm use (Somarriba *et al.*, 2004).

Although there is much variation in the typologies of coffee production systems present in the region, different regions tend to be dominated by one type or another. For example, most of the coffee plantations in the Pacific coasts of El Salvador and Nicaragua have always been grown under a diverse tree canopy (Somarriba *et al.*, 2004) , whereas coffee plantations in Costa Rica tend to have a monoculture shade canopy that is often severely pollarded during the dry season to reduce shading and

³ Data includes only Costa Rica, Nicaragua, El Salvador, Honduras and Guatemala, so the total is probably somewhat higher

serve as an organic input into the soil. Coffee plantations in the Costa Rican highlands (above 1,200 m) rarely have any shade. In addition, there are key differences in the types of tree and plant species incorporated into coffee plantations across Central America. For example, whereas most shade canopies in Costa Rica are dominated by *Erythrina poeppigiana*, *Inga* species tend to dominate plantations in Honduras and El Salvador. In Nicaragua, banana constitutes a very important shade component. The species present in coffee shade plantations is often skewed towards species that provide important products (e.g. timber, firewood, fruits) and services (e.g. nitrogen fixation) to farmers.

The impact of coffee systems on biodiversity conservation depends on the way the system was established (particularly whether or not the coffee trees were established beneath an existing forest, resulting in the clearance of the forest understory or whether the coffee was established in a previously deforested area), the type of coffee plantation established (sun, shade, etc.), the degree to which the farm retains native vegetation in the form of live fences, hedges, or forest patches, and the management of the coffee plantation. Historically, coffee has been the driving force behind much of the region's deforestation in middle elevations where coffee production is most profitable. For example, in El Salvador which has been highly deforested and fragmented, most of the country's so-called forest cover is actually shade-grown coffee (Somarriba et al., 2004). Clearly, in these areas, the most immediate impact of coffee on biodiversity has been the reduction and often fragmentation of the native habitat.

The degree to which coffee plantations include native vegetation may be critical to the overall impact these plantations have on biodiversity, as the abundance and diversity of woody vegetation within the farm will influence the number of niches, resources and habitat types available for additional plant and animal life (i.e. the 'associated biodiversity'). Tree and plant diversity within coffee plantations is highly variable, depending on the type of plantation and its management. For example, studies by Somarriba *et al.* (2004) found an estimated tree species ranged from 19-49 plant species in Costa Rica, and between 92 and 136 plant species in coffee plantations in El Salvador. Other studies of coffee plantations in Puriscal, Costa Rica recorded a total of 82 plant species in 117 coffee farms and 261 tree species in Salvadorian coffee shade canopies (Somarriba et al. 2004). Twenty five *Inga* species are known to be used in the shade strata of neotropical coffee plantations. Weed species richness can range from 20 to 90 plant species per plantation (a total of 84 weed species were reported from coffee plantations in Puriscal, Costa Rica; Mora-Delgado and Acosta, 2001 cited in Somarriba, 2004). The most commonly represented weeds include species in the Acanthaceae, Amaranthaceae, Asteraceae, Cucurbitaceae, Fabaceae, Gentianaceae, Malvaceae, Poaceae, and Rubiaceae (Reddy and Reddy, 1980 cited in Somarriba, 2004).

Numerous studies have shown that the diversity of bird, mammal and even insects is positively correlated with the floristic and structural diversity of the coffee plantation, with diverse agroforestry systems hosting significantly higher numbers of these species (and greater species richness) than plantations lacking a tree component (Perfecto *et al.*, 1996). For example, studies of bird populations in coffee plantations in Central Guatemala by Greenberg and colleagues (1997) found that shade coffee plantations hosted 73 bird species compared to 65 in sun coffee plantations and 8-122 in forest habitats. Not only is the number of tree species important, but also what species are present. Some species, such as *Inga* spp., are known to be important sources of food for nectivorous birds.

Chemical use within coffee plantations is also critical. Not only does the use of herbicides, pesticides and insecticides negatively impact soil and plant diversity within the plantation, but these chemicals often move into streams and rivers, affecting aquatic communities downstream and in some cases, even the near-coast marine systems where these sediments are transported. The use of agrochemicals within

coffee plantations depends on the planted coffee variety and the amount of tree shade within the plantation.

Cattle

Livestock grazing is one of the most widespread land uses in Central America and is arguably the land use that has had the greatest impact on regional biodiversity. From 1960 to 1980, cattle production in the region increased 2.4 times, Homan, 1994). Approximately 26% of the land (13 million ha) is currently under pastures and in many areas pastures are still expanding, particularly in the Caribbean lowlands (Gomez-Pompa *et al.*, 1993, FAOSTATS, 1997; CCAD, 1998). For example, in the Atlantida region of Honduras, the cattle population increased 433.8% between 1952 and 1993, from 27,583 to 147,233 head, although the increase in pasture land was only 260% over the same period (Humphries, 1998). Cattle expansion continues in certain regions of Central Nicaragua (e.g. Jinotega, Zelaya), Guatemala (Petén, Izab'al) and northern Honduras (Colón, El Paraiso, Olancho and Yoro; Szott *et al.*, 2000).

Although there are differences across regions, in general there are three types of cattle production systems in Central America- beef producers, dual-purpose systems and specialized dairy systems- each of which has certain general characteristics (French, 1994). Beef production systems are generally large farms (>100 ha) that are extensively managed with low stocking rates and occur in the lowlands. Most of the cattle are fed with grass, with little or no supplementation. In contrast, specialized milk production systems are generally smaller (for example, in Costa Rica, 70.2% of the dairy farms were <20 ha in size, French 1994) and more technified, with improved grass species, supplementation with concentrates, and improved cattle stock (usually Holstein and Jersey cows in the highlands, and crosses of Zebu with Holstein and Brown Swiss in the lowlands). The final system- dual purpose- is intermediate in its degree of technification, using both native and improved grasses but no supplementation, is generally practiced on small farms (like dairy farms), and occurs mainly in the lowlands (below 900 m). In all systems, the general animal stocking rate is low (1.03 animal units per ha in 1980 for the region, French 1994), though this varies from 0.65 in Honduras to 2.36 in El Salvador (where land is limited and the farmers have had to increase productivity by supplementing cattle; French, 1994). Although in many production systems, cattle are the main agricultural activity, many cattle farmers combine cattle production with crop production, and these systems should therefore not be considered separately (Nicholson *et al.*, 2001).

The transformation of forests to pastures and agricultural lands has had profound ecological impacts in the region, changing the species composition of communities, disrupting ecosystem services (including nutrient cycling, pollination, pest control, water release), altering habitat structure, aiding the spread of exotic species, isolating and fragmenting natural habitats, and changing the physical characteristics of both terrestrial and aquatic habitats (Fleischner, 1994; Noss, 1994). Additional consequences include nutrient loading, agrochemical pollution, acidification, salinization of soils, eutrophication of surface waters and emissions of greenhouse gases (Blake and Nicholson, in press). These changes, in turn, have often resulted in the changes and/or the reduction of both local and regional biodiversity.

Another important adverse impact of livestock production systems is that many pastures are quickly degraded by inadequate management (or inappropriate land use of fragile sites) leading to pasture degradation (loss of vegetative cover, reduction of soil fertility, increased soil erosion, soil compaction and desertification). While there is consensus that pasture degradation is a serious problem throughout the region, no reliable data exist on the proportion of degraded lands, with estimates ranging from 3 to 60% of all pastures (Szott *et al.*, 2000).

A final negative environmental impact of cattle is their role in contributing to greenhouse gas emission (particularly carbon dioxide, methane and nitrous oxide). Cattle production systems contribute to carbon dioxide levels through the conversion of forests to pasture, periodic burning of pastures, and the use of fossil fuels for livestock-related manufacturing, transportation and feed production (Nicholson *et al.*, 2001). Livestock production also produces methane from fermentation in the rumen and manure production, and nitrous oxide emissions from animal manure (Nicholson *et al.*, 2001).

The way in which cattle production systems are managed can have important consequences for biodiversity conservation and the impacts of any system are likely to be site-specific. In particular, management factors such as the use of chemicals (herbicides, pesticides or fertilizers), the use of burning to stimulate pasture regrowth, and stocking rates may determine the negative impact of cattle production both on and off site. For example, in many regions farmers routinely burn their pastures to promote pasture regrowth, control weeds and pests, and release nutrients from grass biomass and in the process destroy habitats for biodiversity and release large quantities of carbon (a greenhouse gas) into the atmosphere (Blake and Nicholson, in press). Anthropogenic fires (both accidental or intended) often escape cultivated fields and pastures, and may encroach into remaining forest fragments or natural habitats. With each cycle of burning, the edges of forest fragments become more vulnerable to fires and more likely to ignite (Laurance *et al.*, 2002 cited in Blake and Nicholson, in press; Kaimowitz *et al.*, 1994). Differences in cattle species, the number of animals per land and use of purchased inputs (feed and fertilizer) may also impact the degree to which livestock production systems contaminate the environment.

Banana

Banana production is another important land use within Central America and has undoubtedly had an important impact on natural habitats and communities throughout the region, particularly in the lowlands near coastal areas. Banana production fall into two distinct categories- those produced as a subsistence crop and those grown for export- and the type of production greatly affects their environmental impact. When grown as a subsistence crop, bananas are usually interplanted with other food or tree crops (e.g. coffee, citrus, cocoa, coconuts or maize), grown on a small –scale and require little (if any) pesticide use, and have a minimal impact on biodiversity. In contrast, when bananas are produced for export, the plantations are usually very large (usually > 300 ha in size), intensive monocultures that receive high inputs of fertilizers and pesticides. It is these large-scale, monocultures that cause the greatest negative impact on biodiversity and which are discussed below in greater detail.

Banana production can affect biodiversity loss through the clearing of primary forest for plantation establishment, the modifications in soil structure and draining systems that accompany the establishment of the plantations, excessive pesticide and fertilizer use which leads to the pollution of soil and water resources, soil erosion and degradation, and the inappropriate disposal of both organic and synthetic wastes (Astorga, 2004; Clay, 2004). In Central America, almost all of the banana plantations were established on previously forested lands, resulting in large-scale deforestation. As banana plantations tend to become degraded within 20 to 30 years due to the intensive production and heavy fertilizer and pesticide use, these plantations are eventually abandoned or allowed to fallow for several decades and new areas must be cleared, resulting in greater deforestation. Thus, while the total area of banana production has remained quite stable over time, the actual areas under banana cultivation continuously

change as banana plantations slowly erode the remaining forest cover in the region. For example, in the Limon province of eastern Costa Rica where bananas are produced for export, almost all of the area under banana production shifted to new lands between 1979 and 1992, as old, degraded banana plantations were abandoned and new plantations carved from the remaining primary and secondary forests (Clay, 2004).

In addition to resulting the removal of large areas of forest, the establishment of banana plantations requires the plowing of land, the construction of contours or terraces, and the establishment of a drainage system to prevent flooding of banana plants, and these changes result in important changes in soil topography and hydrology. In particular, new canals are often created within the banana plantations and small streams diverted to deliver water to banana plantations in the dry season, and these changes may affect aquatic communities (though little information is available to assess how great an impact these changes have). Since almost all weeds and other ground cover within banana plantations is removed with herbicides, soil erosion is also a serious problem and can result in high siltation rates of nearby streams (Clay 2004).

Perhaps the most detrimental effect of banana production is the heavy use of pesticides, including many products that are either mildly or severely toxic to wildlife. Of all agricultural systems, bananas use the highest level of pesticides (particularly herbicides and nematicides), not only to control disease and pests but also to prevent external blemishes on bananas that reduce their export value. In general, farms use herbicides to control weed populations, nematicides to control nematodes that attack the roots of banana plants, fungicides to prevent disease, and insecticides (in plastic bags) to prevent insects from damaging banana fruits. Banana production in Costa Rica has the highest level of pesticide use of any agricultural activity, with up to 44 kg of pesticides being applied per hectare annually (Astorga, 2004). These pesticides include fungicides that are applied both pre and post-harvest, nematicides, herbicides and insecticides, many of which are toxic to wildlife. Although it is difficult to get precise information on the quantities used, Astorga (2004) reports that most banana plantations in Costa Rica spray fungicides 40 to 50 times per year (from the air), apply nematicides directly onto the soil once or twice a year, and apply herbicides in cycles of approximately 8 to 10 weeks. Clay (2004) reports that over 286 different pesticides are authorized for use on banana plantations in Costa Rica either directly on the farm or in the packaging centers. Pesticide use in banana plantations in Belize is similarly high, with banana companies generally mixing all of the pesticides together and spraying their plantations with this toxic mixture usually once a week (Clay, 2004). This heavy use of pesticides leads to the accumulation of pesticide residues and heavy metals such as copper in the soils over time, and degrades soils. In addition, much of the pesticides seeps into ground and subterranean waters, and ends up in rivers, streams and eventually near-coast marine systems. For example, in Costa Rica, toxic residues of heavy metals, organo-chlorines, Clorotalonil, Paraquat and others, have been detected in soil, water, sediments and fish in areas within banana plantations, and through river and streams in the Atlantic banana-growing regions (Astorga 2004). Studies of water in the wells and rivers of the Valle de la Estrella, Costa Rica, have similarly reported levels of Cholortanlonil in concentration of up to 8 ug/l (levels of 3 to 6.5 ug/l are known to adversely affect fish life), and studies in the microbasins of the River Suerte in Costa Rica found that most canals and drainage ditches in banana plantations contained Thiabendazol, Popiconazol, and Imazalil, Thriaendazol and Imgazalil, all productos commonly used within the plantations.

Since many of these agrochemicals are highly toxic for aquatic organisms, birds, reptiles, bees, livestock and other organisms, it is likely that both terrestrial and aquatic organisms are severely affected both

within banana plantations and in surrounding areas. The dead fish that are commonly observed after banana plantations are sprayed, are just one indication of the potential negative effects on biodiversity (Astorga, 2004). Studies in other regions have shown that insecticides, fungicides, herbicides and synthetic fertilizers are the second greatest threat to amphibian communities, after deforestation (Bach 2000 and citations within). While direct data on the effects of pesticide use on animal populations in banana plantations is not available, a study of amphibian populations found that organic banana farms had significantly more amphibian species (13 compared to 9 and 3 in the conventional banana farms), greater abundance of amphibians and a larger number of species found in the leaf litter than conventional farms that used pesticides (Bach, 2000). Other studies indicate that many of the commonly used pesticides are toxic to fauna; for example the pesticides Braco (clorotalonil) is known to be extremely toxic to fish and lightly toxic to birds, Furadan (carbofuran) is extremely toxic to both fish and birds, Dithan (Mancozeb) is extremely toxic to fish and mildly toxic to birds, Baycor and Calisin (Tridemort) is extremely toxic to fish and mildly toxic to birds, and Roundup is moderately toxic to fish and mildly toxic to birds (Bach, 2000).

A final important impact of banana plantations is the improper disposal of wastes, both organic and non-biodegradable. Banana plantations generate large quantities of organic wastes (shoots, flower, the crown, leaves, stems, and second quality bananas) that must be disposed of. Usually these wastes are simply piled up and allowed to rot, and as this rotting material enters streams it consumes the available oxygen and causes fish death (Astorga, 2004; Clay 2004). Non-biodegradable wastes, such as plastic bags, string, tape, and agrochemical containers, are another key source of water contamination. These wastes are stored, recycled, or burned (leading to air contamination), or alternatively left in large open dumps. With heavy rains, these materials are often transported into rivers and streams and carried to sea where they pose an important threat to marine life, particularly turtles which often mistakenly swallow plastic bags and choke. These materials also pose threats to corral reefs.

Due to the enormous negative impacts of conventional, commercial banana plantations on both terrestrial and aquatic biodiversity, the Conservation Agricultural Network (CAN) has developed a series of standards and indicators for sustainable banana production, which includes standards and indicators for ecosystem conservation, wildlife conservation, fair treatment and good conditions for workers, minimal, managed use of agrochemicals, complete, integrated management of wastes, conservation of water resources, soil conservation, environmental planning and monitoring, as well as indicators of favorable treatment of farm workers (CAN, 2001). These detailed standards include a ban on deforestation for the establishment of new areas of banana production, the protection and recuperation of natural habitats on farms, the reforestation or conservation of vegetation along banks of rivers, ravines and other critical areas, the establishment of corridors of native vegetation to unite forest fragments and allow wildlife to migrate between parks, the protection of refuges and other protected areas, the implementation of strategies to protect and recuperate biodiversity, among others. In regards to pesticide use, CAN recommends limiting the use of agrochemicals to minimize their impact on natural ecosystems, soil quality, water resources and local communities, by using integrated pest management, only using agrochemicals that have been approved by the US Environmental Protection Agency (EPA) and national agencies, and prohibiting the use of pesticides classified in the “Dirty Dozen” list established by the Pesticide Action Network. They also provide detailed instruction of how to best transport, store and apply agrochemicals to minimize their negative impacts, and how to protect rivers from sedimentation and contamination.

Sugarcane

Sugarcane is another crop that has impacted (and continues to impact) natural communities in Central America. Although sugarcane is present in almost all of the Central American countries, it is particularly important in Belize where it accounts for more than 50% of its agricultural land and in Costa Rica where it accounting for 10-24% of agricultural land. (Clay 2004). Sugarcane is usually grown in large (usually several hundred hectares or more) monocrop plantations, often on steep land. Generally all remnant vegetation (even including riparian vegetation) is eliminated from the area prior to the establishment of the plantation and frequent weeding and periodic fire use prevent trees from colonizing these areas; consequently sugarcane plantations are usually completely devoid of any tree cover.

The main impacts of sugarcane on biodiversity, historically, have been the conversion of natural habitats to sugarcane production. However, in most regions, land that is currently covered with sugarcane was previously either pasture or agricultural land and only rarely are sugarcane plantations established directly on newly deforested areas. Sugarcane has important impacts on soil as areas are completely stripped bare of cover before planting, and the soils dry out, affecting microorganism diversity and mass and leading to soil erosion (Clay 2004). Soil erosion is often considerable within sugarcane plantations, particularly if they are located on steep slopes, and the combination of silt and excess nutrients from fertilizers contaminate local water supplies. Pesticide runoff from sugarcane plantations can also pollute water (Clay 2004). Another problem is that the regular use of fire in sugarcane plantations to eliminate the lower leaves of plants and to kill or scare off snakes before harvesting, kill any wildlife occurring within the plantations. Some fires may also escape into surrounding areas affecting remnants of natural vegetation.

Because sugarcane plantations are often located in the lowlands near coastal areas, they have had a particularly important impact on coastal systems. As Clay 2004 notes“.. sugar production has changed coastal hydrology. Siltation from soil erosion has clogged coastal ecosystems, especially coral reefs and sea grass beds, which are important to a wide range of species. Nutrient runoff from sugar cultivation has led to nutrient loading and eutrophication of freshwater and marine systems. Finally, sugar mills are cleaned periodically and the organic matter that is flushed can tie up all oxygen in nearby rivers as it decomposes. This in turn asphyxiates fish and other aquatic organisms” (Clay 2004). Although the effects of sugarcane plantations on water quality and aquatic organisms are commonly known, there are few studies that document the precise nature and persistence of this effect.

Appendix 11. Table summarizing best management practices for different agricultural commodities, based on Clay (2004).

Commodity	Major environmental impact	Best management strategies
Bananas	<ul style="list-style-type: none"> - Conversion of primary forests - Soil erosion and degradation - Agrochemical use - Solid waters - Water use 	<ul style="list-style-type: none"> - Manage plantations for continuous cultivation - Reduce use of agrochemical inputs - Identify appropriate integrated pest management programs to reduce the use of pesticides - Reduce fertilizer use - Produce packaging materials on site when possible - Reduce wastes - Use sediment ponds to control runoff - Enforce preservation of riparian buffer zones
Cattle	<ul style="list-style-type: none"> - Habitat conversion - Overgrazing - Feedlot production - Production of feed grains 	<ul style="list-style-type: none"> - Site and construct operations well - Avoid overgrazing - Protect riparian areas - Improve assimilation of feeds - Improve water management - Align production needs with natural processes - Reduce use of chemicals and antibiotics - Produce cattle with less fat and leaner meat - Encourage integrated farms with higher carrying capacity - Improve pasture management and rotations - Protection or improve water quality
Cassava	<ul style="list-style-type: none"> - Habitat conversion - Soil erosion and degradation 	<ul style="list-style-type: none"> - Reduce habitat conversion - Reduce soil erosion
Cocoa	<ul style="list-style-type: none"> - Conversion of primary forest habitat - Soil erosion - Some use of chemicals 	<ul style="list-style-type: none"> - Shape the expansion and maintain the viability of shade cocoa - Increase the efficiency of agrochemical use - Diversity sources of income - Reduce water and/or create by-products - Encourage full-sun cocoa on degraded lands - Work with governments to control cocoa expansion - Work with companies to 'green' their supply chain
Coffee	<ul style="list-style-type: none"> - Conversion of primary forest habitat - Soil erosion and degradation - Agrochemical use and runoff - Effluents from processing 	<ul style="list-style-type: none"> - Halt the expansion of coffee production in natural forests - Discourage the conversion of shade-grown coffee to sun coffee - Diversity production and sources of income - Incorporate fallowing strategies - Reduce input use - Reduce water use in processing - Reduce soil erosion
Maize (maize)	<ul style="list-style-type: none"> - Habitat conservation - Soil erosion and degradation - Agrochemical inputs - Water use and pollution 	<ul style="list-style-type: none"> - Adopt conservation tillage - Increase organic matter in the soil - Use microorganisms to break down water and excess nutrients - Reduce use of fertilizers and pesticides - Use crop rotations
Sorghum	<ul style="list-style-type: none"> - Habitat conversion - Soil erosion and degradation - Agrochemical use - Poisoning in herbivorous animals - Fire hazards 	<ul style="list-style-type: none"> - Build the soil - Reduce pesticide use - Develop payments for carbon sequestration - Manage silage to avoid toxicity - Treat effluent from silage

