ESTIMATING BASELINE CARBON EMISSIONS FOR THE EASTERN PANAMA CANAL WATERSHED*

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Abstract. To participate in the potential market for C credits based on changes in the use and management of the land, one needs to identify opportunities and implement land-use based emissions reductions or sequestration projects. A key requirement of land-based carbon (C) projects is that any activity developed for generating C benefits must be additional to business-as-usual. A rule-based model was developed and used that estimates changes in land-use and subsequent C emissions over the next twenty years using the Eastern Panama Canal Watershed (EPCW) as a case study. These projections of changes in C stocks serve as a baseline to identify where opportunities exist for implementing projects to generate potential C credits and to position Panama to be able to participate in the emerging C market by developing a baseline under scenarios of business-as-usual and new-road development. The projections show that the highest percent change in land use for the new-road scenario compared to the business-as-usual scenario is for urban areas, and the greatest cause of C emission is from deforestation. Thus, the most effective way to reduce C emissions to the atmosphere in the EPCW is by reducing deforestation. In addition to affecting C emissions, reducing deforestation would also protect the soil and water resources of the EPCW. Yet, under the current framework of the Clean Development Mechanism (CDM), only credits arising from reforestation are allowed, which after 20 years of plantation establishment are not enough to offset the C emissions from the ongoing, albeit small, rate of deforestation in the EPCW. The study demonstrates the value of spatial regional projections of changes in land cover and C stocks: ⋆

- The approach helps a country identify its potential greenhouse gas (GHG) emission liabilities into the future and provides opportunity for the country to plan alternative development pathways.
- It could be used by potential project developers to identify which types of projects will generate the largest C benefits and provide the needed baseline against which a project is then evaluated.
- Spatial baselines, such as those presented here, can be used by governments to help identify development goals.
- The development of such a baseline, and its expansion to other vulnerable areas, well positions Panama to respond to the future market demand for C offsets.

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- It is useful to compare the projected change in land cover under the business-as-usual scenario to the goals set by Law 21 for the year 2020.

Suggested next steps for analysis include using the modeling approach to explore land-use, C dynamics and management of secondary forests and plantations, soil C gains or losses, sources of variability in the land use and C stock projections, and other ecological implications and feedbacks resulting from projected changes in land cover.

Keywords: carbon baselines, carbon benefits, land-cover change, Panama, regional analyses, spatial projections, tropical deforestation

1. Introduction

The storage of carbon (C) has become a newly recognized value of forests as concern increases over rising levels of atmospheric concentrations of carbon dioxide (Bloomfield et al. 2000; Gitay et al. 2001). To participate in the potential market for C credits based on changes in the use and management of the land, one needs to identify opportunities and implement land-use based emissions reductions or sequestration projects. A key requirement of land-based carbon projects as articulated in the UNFCCC Kyoto Protocol (Article 12, also known as the Clean Development Mechanism) is that any activity developed for generating C benefits must be additional to business-as-usual. A projection of the business-as-usual scenario of land-use change along with the resulting changes in C stocks on the land can be used to demonstrate this requirement. To date, baselines for existing pilot C projects have generally been estimated by project developers and tend to be project specific (Brown et al. 2000b). For example, most projects developed under the UNFCCC Activities Implemented Jointly (AIJ) pilot phase have used project-specific, bottom-up baselines (Moura Costa et al. 2000). Setting project-by-project baselines has disadvantages because it tends to make transaction costs high, produce baselines that may favor the developer (i.e., one that overestimates the carbon benefits), and may ignore factors occurring at larger scales that could affect the project's baseline. On the other hand, regional-scale baselines by project type would incur lower investment costs, would provide opportunity for respective country or state governments to decide on the type of projects they feel would lead to sustainable development for the region under question, and would likely result in more credible baselines. The regional spatial modeling approach that we present here is one approach for developing such a baseline, using the Eastern Panama Canal Watershed (EPCW) as a case study. The advantage of the spatial modeling approach is that it not only projects how much carbon is being emitted or removed by changes in use and cover of the land, but it also projects where this is happening, and, as such, can identify locations suitable for developing C projects.

Completion of the Panama Canal in 1914 led to recognition of the importance of the Panama Canal Watershed (PCW) that supports the millions of gallons of water required for each ship to pass through the Canal. In addition, the Panama

Canal Watershed is widely acclaimed for its ecological importance (Condit et al. 2001). Today the watershed is home to many of the people living in Panama, for it borders the cities of Colón and Panama City. The watershed supports suburban life as well as agriculture, ranching, and forestry.

At the end of 1999, the operation of the Panama Canal was turned over to Panama. The Panama Canal Authority is now responsible for permitting land-use changes in the watershed if they affect water resources. Some of the watershed is undergoing rapid changes in land use. There is concern about the compatibility of urban and economic development with hydrological needs and conservation of the watershed (Condit et al. 2001). Human activities such as those in the EPCW can affect future ecological resources, and thus the C storage potential. The analysis presented here is designed to project land-cover change through 2020 under a business-as-usual and a new-road development scenario. This analysis provides a projected baseline to identify where opportunities exist for implementing potential projects to generate potential C benefits.

We developed a rule-based model to project land-cover dynamics in the EPCW that assumes current land-cover trends will continue into the future. The rules include enforcement of environmental protection in the parks or other protected areas. The business-as-usual scenario provides a baseline against which to evaluate implications of changes in management practices. The rule-based geographic information systems model projects land clearing specific to the environmental conditions and land-use practices of the EPCW over the next 20 years. The projections map patterns of deforestation and reforestation based on current land cover patterns, distance from permanent roads and population centers, population growth, and past land-use trends. Some factors that can exert pressure on the environment are not part of the current model (e.g., economic and technology changes). The new-road scenario includes the establishment of the new bridge and completion of the Transisthmian highway between Panama City and Colón.

Our analysis focuses on projecting the effects that land use may have upon land-cover change and C storage in the EPCW. Our project is part of a larger effort to assess the ability of Panama to develop C sequestration projects in the EPCW.

2. Background

2.1. THE ENVIRONMENT OF THE EASTERN PANAMA CANAL WATERSHED

The Eastern Panama Canal Watershed (EPCW) used in our analysis contains 339,638 ha of largely forested land. This eastern portion is the hydrologic and historic watershed, but the legal watershed was defined more expansively in 1999. This seasonally wet area of the tropics experiences a dry period from December through April. The vegetation is classified mainly as tropical moist forest according to the system of Holdridge (1967). Yet, there are climate and vegetation differences within the watershed that have contributed to its high biodiversity (Condit et al. 2000). The Caribbean side of the isthmus has more rainfall and a shorter dry season. There is a gradient in deciduousness across the isthmus reflecting the rainfall and dry season, with forests near the Pacific coast being about 25% deciduous and forests near the Caribbean having few deciduous trees.

Historic patterns of land use in the watershed are quite diverse (Condit et al. 2001). The Pacific slopes of the watershed were settled more than 7000 years ago by indigenous groups and later by Spaniards who grew subsistence crops such as corn and beans. In the early 1900s these practices were abandoned, and forests were reestablished. However, close to Panama City, the forests remain fragmented. Mature forests remain in much of the EPCW, particularly in the northeastern part of the watershed.

2.2. CHANGES IN NATURAL RESOURCES

Forests currently cover 158,000 hectares (54%) of the EPCW used in our analysis. Most of the remaining area is pasture, agriculture, or scrubland. Some of the forest has been lost to establishment of urban areas. In the rural areas, forest land is being converted into agriculture using fires to prepare the site for planting by burning off remaining woody materials. However, because of the poor quality of much of the soil, the agricultural areas are subsequently often converted to pasture land. Between the 1980s and 1998, satellite imagery shows that 1.7 to 3% of forests per year changed to pasture, agriculture, or scrubby vegetation and 0.2% per year changed to urban areas (Panama Canal Watershed Monitoring Project 1999).

There is great concern about the status of the forests in the watershed. Landsat Thematic Mapper images of 1973, 1974, 1986, 1987, 1989, 1990, and 1991 established that the forests have decreased by 43% since 1974, from 275,549 ha to 157,063 ha. Tarté (1999) reports the rate of deforestation in 1999 as 573 ha yr^{-1}. Thus, the rate of clearing has declined from the 24-year average of 4,937 ha yr^{-1}. Today 34% of the 375,000 ha of the EPCW is under some kind of protection, such as being maintained as a national park. Furthermore, the regional land-use plan provided by Panamanian Law 21 in 1997 mandates expansion of the protected area to 40% of the EPCW. Almost 69% of the remaining forests are in protected areas, most of which have been established since 1980 when political decisions were made to preserve parts of the watershed by setting them aside in national parks and other protected areas. The Chagres National Park contains 55% of all forests in the EPCW, which represents 80% of all forests in the protected areas. Most of these forests are primary, while those adjacent to the Panama Canal are secondary. There is a noticeable increase in areas covered by secondary forests regenerating in both protected areas and on private lands in the watershed. Even so, these protected areas are a target for human colonization. Although anecdotal evidence of small-scale deforestation abounds, there is no evidence of extensive illegal deforestation. The loss of forests occurs mainly in areas that are undergoing population growth where the National Environmental Authority (ANAM) granted approval for forest cutting.

Commercial plantations began to be established in the watershed in abundance in 1998. As early as 1993, a series of laws for forestry incentives were initiated, leading to cultivation of timber-yielding tree species. Tax deductions are allowed during the first five years of forest investments for plantations. The Interoceanic Region Authority (Autoridad de la Región Interoceánica, ARI) is currently granting concessions for reforestation projects of degraded lands within the watershed. ARI gives away land-use rights for reforestation to the private sector with the intent of reducing erosion and sedimentation. However, because there are no technical requirements to monitor these reforestation projects, there is concern that management of some plantations will be abandoned. Furthermore, anecdotal evidence reveals that mature secondary forests were cut and then replanted as plantations to receive tax deductions under the Forestry Incentives Law.

Historic sediment data suggests that deforestation in the EPCW is likely a source of excess sediment (Panama Canal Watershed Monitoring Project 1999). However, sediment yields and discharge-weighted sediment concentrations generally declined from 1981 through 1995. Although these declines were not correlated to decreases in run-off, they were related to a dramatic decline in the dilution rates for watersheds during that period (Panama Canal Watershed Monitoring Project 1999). The increasing protection and recovery of the forests is related to a gradual but constant decrease in soil erosion and rates of sedimentation in the rivers and lakes. Nevertheless, the quality of water is deteriorating (Panama Canal Watershed Monitoring Project 1999). This decline is largely associated with the 1947 opening of the Transisthmian Highway between the cities of Panama and Colón. Much agricultural, industrial, and urban development occurs along the highway.

Vegetation regrowth is increasing on cattle farms. This reversion likely results from conservation and reforestation policies of the National Bank of Panamá, as required by Panamanian Law 21. The regional land-use plan provided by Law 21 establishes a goal of reduction of cattle farms in the EPCW from 127,000 to 7,000 hectares by the year 2025. This plan will cause a dramatic transformation of land-use in the EPCW. Already tax incentives seem to have curtailed the expansion of cattle pastures that had been occurring since the 1950s. Furthermore, the plan discourages population growth in the EPCW, although, in contradiction, current policies of the Ministry of Housing allow construction in two communities (Chilibre and Las Cumbres) within the EPCW.

2.3. CHANGES IN THE HUMAN POPULATION

Between 1950 and 1990, the population in the Eastern Panama Canal Watershed increased five-fold, from 21,987 to 113,175, which undoubtedly contributed to the need for more transportation routes (Tarté 1999; Panama Canal Watershed Monitoring Project 1999). By 1998, the estimated population was 142,000 (Panama

TABLE I

Geometric projections of the human population in Eastern Panama Canal Watershed by province and sector (based on information in Prieto et al. 1999).

	Projection year		
	2000	2010	2020
Western Atlantic sector of the province of Colón	4,783	5,141	6,918
Eastern Atlantic sector of the province of Colón	36,353	60,644	88,754
Subtotal for Province of Colón	*41,136*	*65,78*	*595,672*
Western Pacific sector of province of Panama	24,534	32,142	52,312
Eastern Pacific sector of province of Panama	87,697	121,058	259,089
Subtotal for Province of Panama	*112,231*	*153,200*	*311,401*
Total for Eastern Panama Canal Watershed	153,347	218,985	407,073

Canal Watershed Monitoring Project 1999). In recent decades the annual population growth rate in the eastern Panama Canal Watershed ranged from a high value of 4.5% for 1960 to 1970 to a low of 3.7% for 1970 to 1980 (Prieto et al. 1999). The rate of increase for 1980 to 1990 for the eastern watershed was 3.8%, compared to a 2.6% population increase for all of Panama (Prieto et al. 1999). Geometric projections from 1990 using the 3.8% rate of growth indicate that population in the EPCW will increase to 407,000 people in 2020 with 24% of the growth in Colón and 763% of the growth in the province of Panama (Prieto et al. 1999) (Table I). The new Law 21 and Law 19 give the Panama Canal Authority the responsibility to regulate anything that might impact the 'hydrological' resources of the watershed; however, no mechanisms exist for population control.

Prieto et al. (1999) have conducted an extensive analysis of the data on human population. The population of the EPCW is primarily distributed into 432 communities. In 1990, 77% of these communities (332) had less than 200 inhabitants, and 17% of the population was settled. Only 15 communities had more than 1,500 inhabitants, concentrating 43% of the population. These highly populated sites were mostly in Chilibre and Las Cumbres. Sixty-two percent of the population is concentrated in a 2.6-kilometer strip on both sides of the Transisthmian Highway.

There is also a growing human population within the protected areas. For example, 2,712 people lived within the borders of Chagres National Park in 1990, with continued population pressure from outside the park likely to induce greater population growth within the park (Prieto et al. 1999).

3. Approaches and Assumptions

In this section we discuss the data sources and approaches that we used for estimating land-cover change and corresponding changes in C stocks.

3.1. PROJECTING LAND-USE CHANGE

The approach for projecting future land-cover change of the EPCW is a rule-based model with the rules derived from existing conditions. Our underlying assumption for the business-as-usual scenario is that existing conditions about the way that people use the land will not change over the next twenty years. The procedure involves projecting where land-cover changes might occur and estimating the amount of land-cover change. Factors that affect land-cover change in the EPCW and that are used in this analysis include human population growth and associated settlement, road distribution, cattle ranching, and establishment of plantations.

3.1.1. *Data sources for land-cover change*

Our model builds upon the large amount of spatially-explicit geographic and environmental data and remote sensing information available for the EPCW collected as part of the Panama Canal Watershed Monitoring Project (1999). A geographic information system (GIS) of the watershed was developed by the Panama Canal Authority (ACP) and contains information on:

- Land cover based upon Landsat Thematic Mapper images from 1973, 1974, 1986, 1987, 1989, 1990, 1991, and 1998 and a set of thirty-one 1-ha plots, eight 1/4-ha plots, and eight 5-km transects in different parts of the watershed.
- Major permanent roads. These roads are buffered by 1.5 km on either side to achieve a 3 km buffer zone around permanent roads in which the major settlements occur.
- Population of each community according to the 2000 census and geometric projections through 2020 conducted by the Canal Watershed Monitoring Project (Prieto et al. 1999).
- Soil aptitude based upon (a) general information on soil suitability for agriculture in eight categories available at the 1:1,000,000 scale for the entire watershed (from the University of Panama) and (b) soil composition information at a scale of 1:150,000 available for approximately 60% of the watershed [from the Panama Agriculture Ministry (MIDA)].
- Waterways (the major rivers, lakes, and canals).
- Locations of plantations including the 756 ha Ecoforest plantations of both teak (*Tectona grandis*) and native species, 120 ha of native species plantations under the Panama Canal Authority, and 74 sites constituting 1,589 ha in 1998 (from Dirección Nacional de Patrimonio Natural (ANAM), Departamento de Conservación de la Biodiversidad).

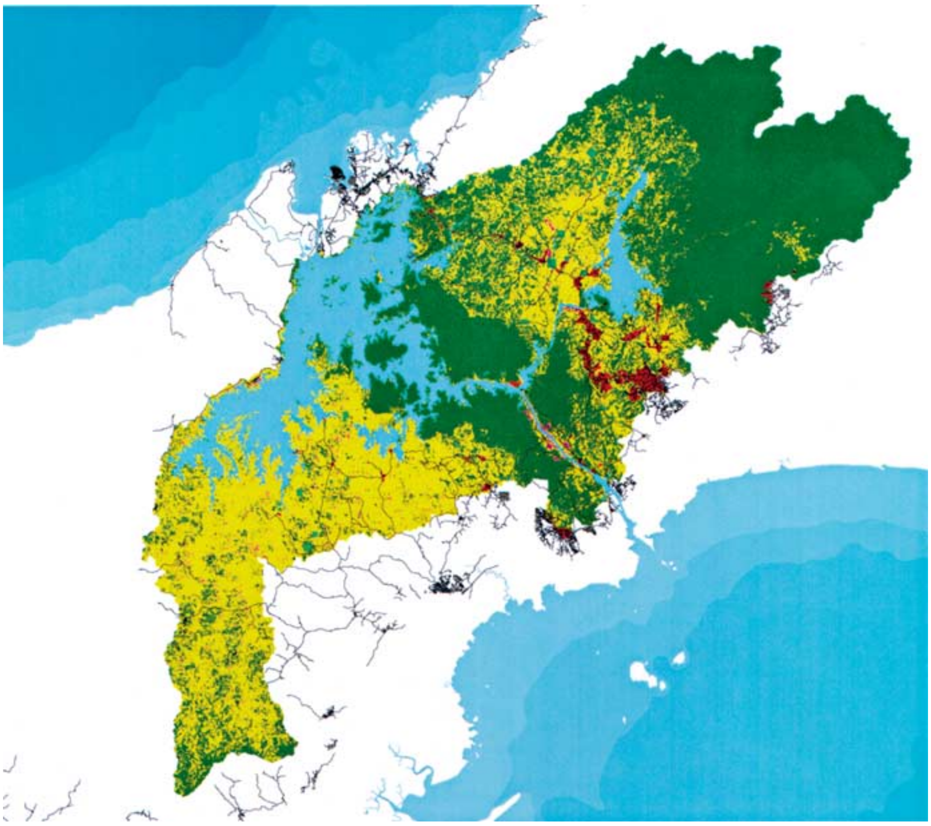

Figure 1. Map of major land-cover categories in 1998 for the Eastern Panama Canal Watershed (green = forest; red = urban; yellow = pasture, agriculture, and scrub; blue = water; and black = roads).

3.1.2. *Major land cover categories*

The land-cover classes for the projection are those that differ in their carbon content: forests, plantations, agriculture/pasture/scrub, bare ground, urban, and water (Figure 1; Table II). The agriculture, pasture, and scrub cover types are combined, for they have similar carbon content and are also difficult to distinguish on the remote sensing imagery. The typical pattern of land-use change in rural areas of the EPCW is the conversion of forested land to agriculture, which eventually becomes pasture (Panama Canal Watershed Monitoring Project 1999). Furthermore, remote sensing data suggests that the pasture land reverts to scrubby vegetation in the southwestern portion of the EPCW. Areas of secondary forest from natural regeneration of abandoned pasture and agriculture lands are not readily identifiable from the remote sensing imagery and were not considered as a separate class.

Plantations are treated as a special category of forest land, for *in situ* data were obtained resulting in a list of the size, location, species and age of plantations in the EPCW. Currently, approximately 2,311 ha are reforested with plantations within the EPCW. The main commercial species used for reforestation in the watershed

TABLE II
Components of major land cover types of the Panama Canal Watershed.

Land cover type	Components
Forest	Primary
	Mature secondary
	Secondary, with little intervention
	Secondary, heavily disturbed
Plantations	Teak plantation
	Native species plantations
	Native species and teak plantations
Pasture/agriculture/scrub/grass	Scrubby vegetation
	Grassy areas (native and nonnative)
	Pastures
	Agriculture
Bare ground	Mineral extraction sites
	Erosion areas
Urban and commercial	Urban areas
	Commercial and industrial sites
Water	Rivers and lakes

is teak, and large plantations are found at various sites. The places most frequently used for cultivation of teak are former cattle farms. Other plantation lands are planted with native species, and some have a combination of native species and teak. The general characteristics of plantations are revealed by considering 55 plantations located within the EPCW that contain a combined area of 1,165.5 ha as of 1998 (data provided by ANAM). Only teak was grown in 67% of the plantations, 19% were a combination of teak and other species, and 8% were a combination of native trees with exotic tree species (other than teak). Three of the plantations are in the Chagres National Park. In general, the plantations are cut on a rotation of 25 years or more.

Most plantations are planted on degraded pasture. Typically, degraded pastures were invaded by the nonnative Vietnamese grass, *Saccharum spontaneum*, which is burned and then planted to tree seedlings. Invasion of plantations by this grass is an ongoing management problem. Because the nonnative grass is highly flammable, it is important to place fire breaks within the plantations to reduce the chance of tree loss. Yet, breaks are not always seen as economically viable and are sometimes not established, which can lead to fires and loss of plantations.

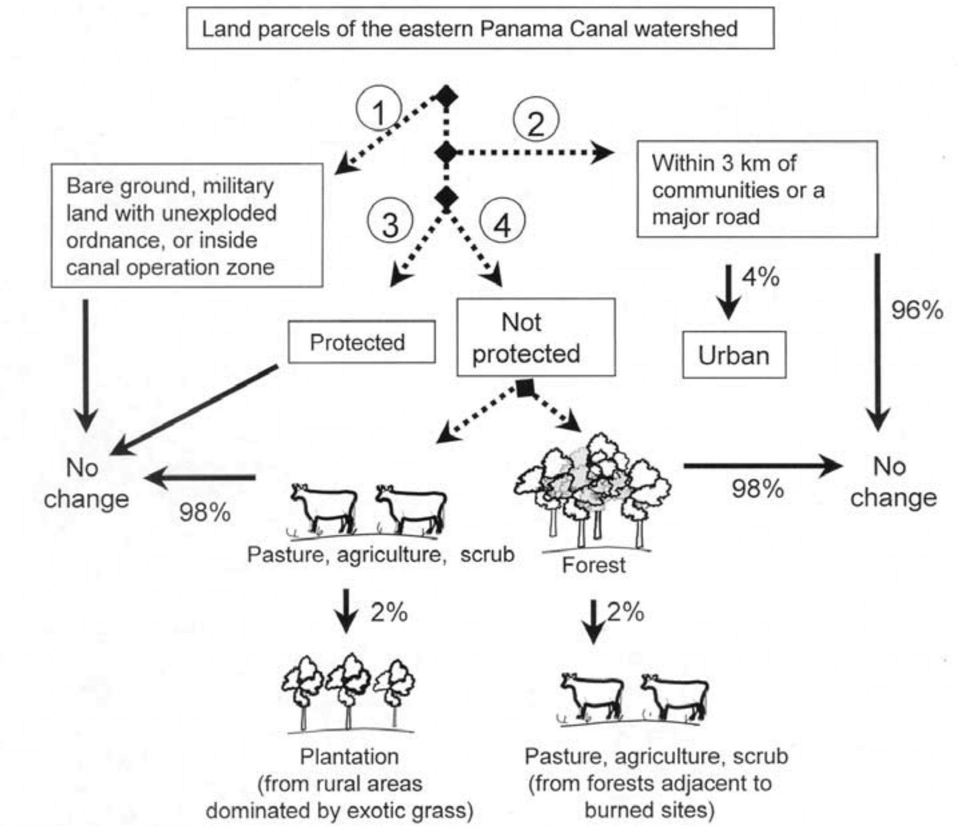

Figure 2. Rules for modeling land-cover change. On a year-by-year basis, the model calculates the area in each of four types of land cover: urban, pasture, forest, and plantation. The rules that drive the model, in order, are: (1) bare ground, military land with unexploded ordnance, wetland, and canal operations do not change from year to year; (2) then the model considers all other areas and lets 4% of that land within 3 km of a community or major road convert to urban use; (3) the remaining protected land (parks) remains unchanged; and (4) 2% of unprotected forest is changed to pasture, and 2% of pasture is converted to plantations. The results at the end of one time step (one year) become the input values for the next time step.

3.1.3. *Estimating land-cover change*

The rule-based model is a multi-step process to estimate annual changes in land-cover over 20 years (Figure 2). Step 1 implements the assumption that land-cover changes do not occur on bare ground, military lands with unexploded ordinance, wetlands, or the canal operation areas. In step 2, there are two areas near human habitations that can undergo changes: (a) areas close to roads and established communities and (b) rural areas that are more than 3 km distance from major permanent roads and from communities with greater than 500 inhabitants. We estimate loss in forest cover due to urbanization will occur at a rate of 4%/year for the nonurban land within 1.5 km on either side of permanent roads and communities of greater than 500 inhabitants. This estimation builds upon a linear extrapolation of the observation that 62% of the population lives within a 2.6 km strip on either side of the existing Transisthmian Highway (Prieto et al. 1999). Law 21 allows for new settlements within the watershed as well. We used estimates of potential locations to establish new communities. Once established in the projection, these new communities are buffered by 1.5 km to set up a zone where land conversion to urban use is likely. Step 3 specifies that those protected areas at a distance from human settlements do not change.

In step 4, 98% of the remaining unprotected forests and pasture/agriculture/scrub areas experience no change. Land changes occur in pastures that are abandoned, which succeed to natural forests or become plantations. Examination of the remote sensing data showed that the annual percentage of change from the pasture/agriculture/scrub land-cover type to forest to be about 2%/yr (the range is 1.5 to 2.6% per year). Pasture lands are more likely to become forests now than in the past because bank loans, which once provided an incentive to maintain pastures, are no longer available. Instead, there is now a tax incentive to establish and manage plantations (for at least 5 years). Potential pasture sites that become plantations are those that support the nonnative grass, *Saccharum spontaneum*. Potential pasture/agriculture/scrub lands that revert to natural forests are selected randomly based on recent trends.

Forests can also become pasture/agriculture/scrub/grass vegetation. We used remote sensing data from the 1980s and 1998 to estimate that the annual percentage of change from forest to the pasture/agriculture/scrub/grass land-cover type was 2%/yr (the range is 1.7 to 3.0% per year). The forest areas undergoing change are placed randomly unless determined otherwise.

Two scenarios are included in the analysis: a business-as-usual projection and the consideration of new roads. The business-as-usual scenario is that there will be no new roads, and the new-road scenario includes establishment of the new bridge and completion of the new Transisthmian toll-road between Panama City and Colón. The new bridge will connect existing secondary roads and greatly facilitate transport across the Canal. Pressures for changes in roads and land-use in the watershed result from a set of development projects that will incorporate land and facilities of the former Canal Zone into national development programs. The most important of these projects will turn the country into a multi-mode center for cargo transportation. Currently, the Ministry of Housing is authorized to build more than 5,000 houses in Chilibre and Las Cumbres alone, in support of such projects. The new roads translate into land-use change in the model because 4% of the land adjacent to roads changes to urban land use each year.

3.1.4. *Factors not included in the analysis*

3.1.4.1. *Effects of soil conditions on location of settlements.* We found that we could not determine an effect of soil type on settlement location. Most communities are located on non-arable soil types, which are the most common soils within the EPCW. However, settlements would be expected to be preferentially located on arable soils. Yet the pattern of settlement distribution does not relate to prime soil conditions, nor is it randomly associated with soil types. Furthermore, there is no soil data for about 40% of the EPCW. More data and analysis would be required in order to attribute settlement patterns according to the different soil conditions in the EPCW.

3.1.4.2. *Forest degradation.* Forest degradation (the loss of biomass, species, or other features, often due to thinning) only rarely occurs in the EPCW and is not included in this analysis. The selective cutting of trees is rare because the forested areas are largely inaccessible because of steep slopes and limited road access and only happens in rural areas where some species are occasionally removed for firewood or furniture. Thus, the forests tend to remain intact and only change via land-cover alterations.

3.1.4.3. *Changes to forested area within the urban land cover.* Urban areas have some forests set aside, and we assume that these isolated green areas do not decline in area or in the amount of C they store. It is possible, however, that urban growth pressures might compromise the integrity of these urban forests.

3.1.4.4. *Climate change effects on forest carbon.* A constant C density is assumed; yet changes in climate and atmospheric concentration of CO_2 could alter the amount of C stored in forests. However there are large gaps in the knowledge of potential changes [e.g., Karnosky (2003)], and the status of global climate models does not allow for regional scale assessments of potential impacts of climate change nor CO_2 enrichment on ecosystem dynamics. King et al. (1997) used a georeferenced model of ecosystem C dynamics to explore the sensitivity of global terrestrial C storage to changes in atmospheric CO_2 and climate. Their model suggested that, with changes in both climate and a doubling of atmospheric CO_2, global terrestrial C would increase on the order of 15–18%. However, the time to reach double CO_2 and the corresponding change in climate is well beyond the 20-year simulation period used in our study. Thus impacts of climate change were not included in our model.

3.1.4.5. *Changes to land use within protected areas.* Although some encroachment has occurred into the forests of the protected areas, we assume that during the projection period there are no changes to the land cover within these areas except where new roads go through protected areas (e.g., the Panama-to-Colón Toll highway goes through a national park). The protected areas are primarily forested, but some other land uses occur in them, particularly associated with human populations along the boundaries (Prieto et al. 1999). There is a growing population within the protected areas. Population pressure from outside the park may induce greater population growth within the park (Prieto et al. 1999). The growth in the western sector of the EPCW has been more dispersed except for the growth in areas near Panama City that occurred in response to the lack of housing in the city.

3.1.4.6. *Effects of new dams.* The Panama Canal Authority is developing plans for two new dams in the western part of the watershed (that is not presently hydrologically connected to the EPCW). Proyecto Chagres would inundate 1,414 ha. Although the final approval of these dams is not yet in place, their creation is argued to be part of the continuing maintenance of the canal waterway. Thus, it would be useful to project the impacts of these dams for the larger region within both the business-as-usual and new-road development scenarios. We do not include projected impacts due to establishment of new dams because the construction and most of the roads and their associated development would not occur in the EPCW.

3.2. ESTIMATING CHANGES IN C STOCKS

We estimated C stocks as the product of the area of each land-cover class at each time step by the corresponding C density (tons carbon per unit area). The change in stock is then calculated as the difference in C stocks between two years. We assumed that urban land had zero C stock in vegetation and soils.

3.2.1. *Carbon densities of native forests*

The ideal database for estimating C densities for large areas of forests is a well-designed forest inventory. The last such national inventory in Panama was done in 1972. Inventories typically report the commercial volume, which can then be converted to biomass C using methods outlined in Brown (1997). Based on the 1972 inventory, the C density of aboveground biomass for the tropical moist forest life zone (the common life zone in the EPCW) was estimated to be 85–183 Mg C ha^{-1}, and for the tropical wet forest life zone (also present in the EPCW), it was estimated at 60–107 Mg C ha^{-1} (Brown 1997). Although this inventory covered areas and life zones common to the EPCW, it was not specific to this area and is almost 30 years old, thus it was not used in our analysis.

Recently, two other studies have measured C densities of aboveground forest vegetation specifically in the EPCW (Gonzalez 2000; Heckadon-Moreno et al. 1999). The study by Gonzalez (2000) measured biomass C in 339 plots scattered across three national parks (Soberania, Chagres, and Camino de Cruces) and in several life zones but with no distinction between mature and secondary forests. No significant difference was found among the mean C density estimates for the three national parks. The study by Heckadon-Moreno et al. (1999) measured aboveground biomass C in trees in 39 plots scattered across the EPCW and in forests identified as mature and secondary. This study resulted in estimates of 177 Mg C ha^{-1} for mature forests and 100 Mg C ha^{-1} for secondary forests.

We only used the data from Gonzalez (2000) because that study was based on a more extensive number of plots, which were assigned to a specific life zone. Given the distribution of plots across the EPCW, we assumed that the estimates reflect the mix of secondary and mature forests in proportion to their occurrence across the watershed. Based on the results of the model simulations, most forest clearing would occur in the lower elevation tropical moist forest life zone. Thus, the mean C density that we used was 126.6 Mg C ha^{-1} (95% confidence interval of ± 15% of the mean) for the lower elevation tropical moist forest life zone. The mean C density is at the middle of the range obtained for this life zone based on the national forest inventory (85–183 Mg C ha^{-1}; Brown 1997).

The mean value of 126.6 Mg C ha^{-1} does not account for belowground biomass or for coarse and fine litter and understory. We increased the aboveground C density by 20% to account for roots (based on Cairns et al. 1997) and by another 12% to account for fine and coarse litter and understory (based on Delaney et al. 1998 and Brown et al. 2000a). This approach resulted in an estimate of the mean total C density for live and dead biomass of 167 Mg C ha^{-1} with a 95% confidence interval of approximately 25 Mg C ha^{-1}.

We do not consider any C emissions from soil due to conversion of forests to agriculture or pasture because there is no reliable information for the soil C content in the EPCW forest soils. Conversion of forests to annual crops can result in up to 40% of the C in the top 30–40 cm being lost in the first five years (Detwiler 1986). However, conversion of forests to pastures appears to result in little to no loss of soil C (Brown and Lugo 1990; Lugo and Brown 1993). Omission of changes in soil C likely results in an underestimate of the C emissions from deforestation.

3.2.2. *Carbon densities in agriculture/pastures/scrub*

Carbon in agriculture/pastures/scrub systems is low compared to other land uses, and few data in tropical humid environments exist. We estimated an average C density in above- and belowground vegetation for this land cover as 1.5 Mg C ha^{-1} based on experience in tropical pastures/scrub and annual crops in Brazil and Belize (S. Brown 2002, unpublished data). Carbon density of annual crops over a yearly cropping cycle where bare soil exists for periods of time is less than 1 Mg C ha^{-1} on average. For pasture, the C density depends on how intensively the land is grazed and can range from less than 0.5 Mg C ha^{-1} for intensively grazed pastures to 2–3 Mg C ha^{-1} for less intensively grazed.

3.2.3. *Carbon densities of plantations*

The dominant plantation type in the EPCW is teak, which covers at least 60% or more of the existing plantations. Kraenzel et al. (2003) measured the C content in above- and belowground components of four 20-year-old teak plantations located in Chagres and Soberania National Parks (Table III). Estimates of C for the plantations are based only on locally derived allometric regression equations for teak.

TABLE III

Carbon content (t C/ha) in above-ground components of four 20-year-old teak plantations located in Chagres and Soberania National Parks (from Kraenzel et al. 2003).

Plantation	Trees	Litter/undergrowth	Total
Chagres-1	105.6	5.8	111.4
Chagres-2	140.6	6.2	146.8
Chagres-3	134.8	5.0	139.8
Sobrania-4	99.8	6.8	106.6
Mean	120.2	6.0	126.2
Standard error	10.2	0.4	10.1

The Kraenzel et al. (2003) database is relatively small yet suggests that the rate of C accumulation is not significantly different between the two parks.

To estimate the changes in C stocks for the lands projected to be converted to plantations over the 20-year period, we estimated the annual rate of C accumulation in the plantations. The rate of C accumulation was assumed to be linear over the 20–30 years of growth of teak (Tectona) plantations based on pan-tropical teak plantation data presented in Lugo et al. (1997). Thus the annual rate of C accumulation used here is 6.3 Mg C ha^{-1} yr^{-1} with an estimated 95% confidence interval of ± 1.3 Mg C ha^{-1} yr^{-1}. The rate of C accumulation in other-than-teak plantations is largely unknown. For this study, we assumed that the estimates are the same as those for pure teak plantations.

To estimate the change in C stocks caused by annual increases in area of plantations, the area projected-to-be-planted every year during the 20-year time frame is tracked separately. The plantations are then ‘grown’ and tracked as C accumulates for each age class. For example, the increase in plantation area during year one of the model simulation accumulates C for the whole simulated period of 20 years, whereas the increase in plantation area during the last year accumulates C for one year only. We did not include any ‘management activities’ in our analysis such as thinning, which would influence the rate of C accumulation in the plantations. The age of plantations existing at the start of the simulation is between 1 to 5 years old. We assumed that they were on average 3 years old at the start of the project and contained 18.9 Mg C ha^{-1}.

Any increases in soil C that may occur as a result of plantation establishment are not included in our analysis because no information on the rate of accumulation of soil C for the EPCW is available. Some experience with C measurements in the soil of teak plantations suggests that they accumulate little to no soil C (S. Brown, unpublished data based on work in teak plantations in tropical humid areas of Venezuela). The reasons for the low rates of soil C accumulation are unclear,

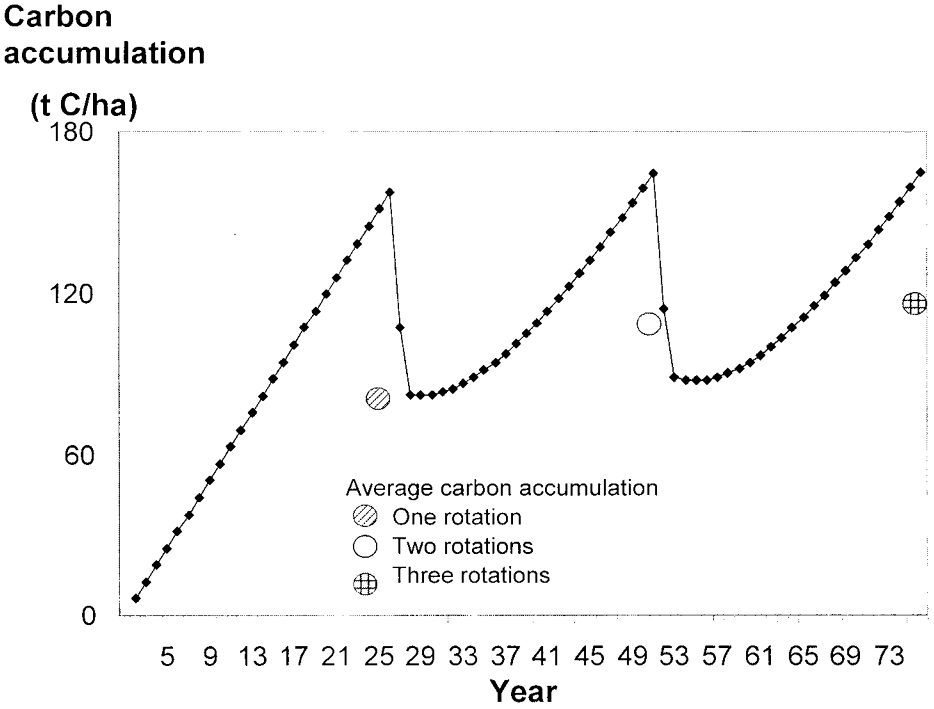

Figure 3. The patterns of C accumulation in teak plantations over three 25-year rotations, showing the gradual increase in C as slash and wood products accumulate from rotation to rotation.

but it has been observed that the leaf-litter layer under teak plantations was thick, indicating that the leaves decomposed very slowly and thus added little to the soil C pool. We further assumed that none of the projected plantations are affected by fire, even though it has been reported that fire can cause damage in plantations, especially in those sites invaded by dense understory of grasses.

Beyond the time period for the model simulations, the plantations are expected to be cut and replanted over a given rotation length. This expectation means that all the C accumulated at the end of the rotation cannot be counted as a C benefit because some of it will be emitted during harvesting and processing of the timber. It has been proposed that, in such situations, only the average stock of C during the rotation period be counted as new C sequestered (see Brown et al. 2000b for further details).

The patterns of C accumulation over three 25-year rotations are shown in Figure 3 to illustrate the average stock of sequestered C. At the end of the first rotation, some slash is left behind after harvesting (assumed to be 40% of the total biomass [Kraenzel et al. 2003]), which then decomposes at a rate of 10% per year (based on data in Delaney et al. 1998, and S. Brown, 2002, pers. comm. based on unpublished field data). The slash does not all decompose during a rotation period and accumulates over time from one rotation to the next. Of the 60% of the total biomass that goes into logs, 30% is assumed to go into long-term wood products, and the rest goes into waste, which decomposes during the year of harvest (Winjum et al. 1998). Thus, over several rotations, the average C stock slowly increases as incomplete decomposition of slash from one rotation to the next accumulates and C becomes sequestered in long-term wood products. During the first rotation, the average C stock is 82 t C/ha, which increases to 112.8 t C/ha at the end of the second rotation, and increases to 115.5 t C/ha at the end of the third rotation. Over how many rotations this pattern of accumulation would continue is unknown and depends on future site preparation (e.g., it is possible a site would be burned to clear it of slash between rotations), the rate of decomposition of the slash (which could vary between about 5–15% per year), and the rate of decomposition of long-term wood products (these are not permanent storages as there is a slow but positive rate of turnover of long-term wood products [Winjum et al. 1998]).

4. Results and Discussion

4.1. LAND-COVER CHANGE PROJECTIONS

The projections result in major land cover changes within the EPCW over the next twenty years for the urban areas; plantations; and the lands in pasture, agriculture, or scrub. The forest area gradually declines. The projected areas contain some places with no data, for heavy and consistent cloud cover precluded some places from satellite observation.

Most of the land-cover change occurs where the majority of the roads and communities are located (Figure 4a). The land divided among pasture, agriculture, and scrub changes in both amount and location. Most (80%) of the land that becomes urban derives from the pasture/agriculture/scrub category. At the same time, every year 2% of the forest land becomes pasture/agriculture/scrub, and 2% of the pasture/agriculture/scrub becomes plantations. Thus, there is a consistent loss of native forest land that ultimately ends up as plantations.

Under the new-road scenario, the greatest land-cover changes occur near the new highway (Figure 4b), but there are relatively few differences in this case as compared to the business-as-usual case. The greatest difference in cover changes for the two projections is the increase in urban lands and decline in plantations and pasture/agriculture/scrub for the new-road scenario (Figure 5).

These projections of land-cover changes can contribute to an understanding of a variety of environmental issues. The model could provide a basis for analyzing how different management practices of the land influence changes in C stocks. This analysis requires spatially-explicit information on the distribution of ownership and better understanding of how different types of agricultural owners clear and farm the land. These data are now being collected. The model could also be used to

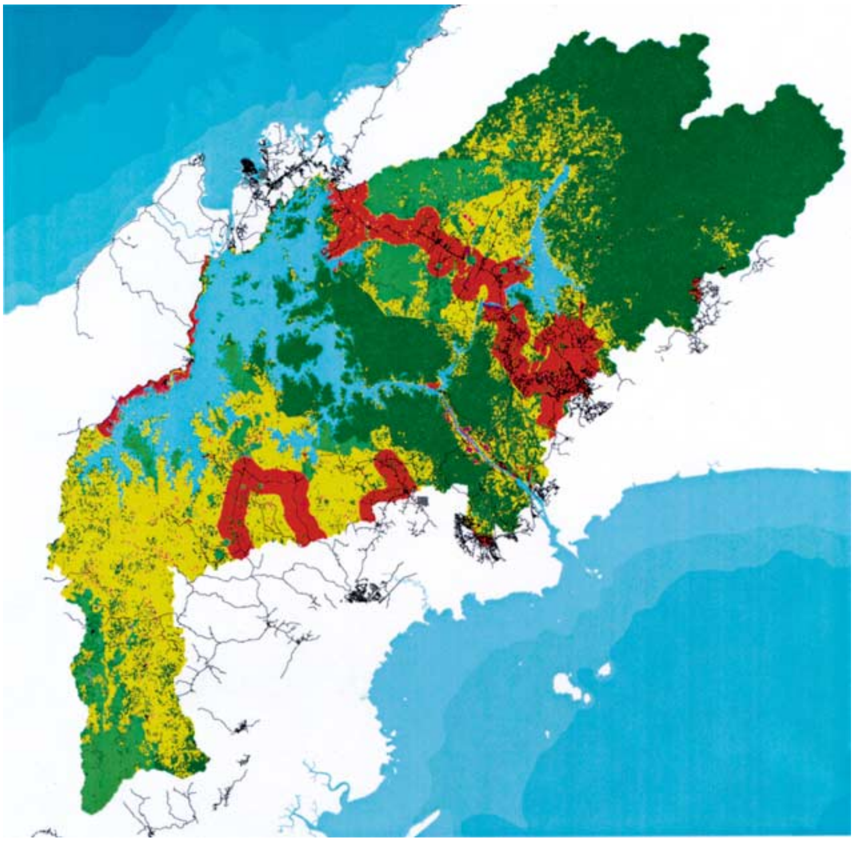

Figure 4. Map of projection for 2020 scenario, showing the major land cover categories under the (a) business-as-usual and (b) new-road scenarios (dark green = forest; light green = plantations; red = urban; yellow = pasture, agriculture and scrub; blue = water; and black = roads).

analyze how management of the protected areas would influence land-cover change and C stocks. The effectiveness of various conservation measures and approaches could also be evaluated.

4.2. CHANGES IN CARBON STOCKS

The projected areas of each land-cover type for the two scenarios were combined with the C density data as described above to project the change in C stocks – decreases in C stocks are counted as emissions and increases in C stocks as removals (C sequestered). For the business-as-usual scenario, C emissions from deforestation gradually decline over the 20-year period, from about 160,000 ha yr^{-1} during the first five years to about 130,000 ha yr^{-1} during the last five years (Figure 6). Carbon emissions from deforestation could be lower if secondary forests were preferentially cleared over mature forests because the secondary forests would have lower C stocks. Clearly, better identification of secondary forests and their

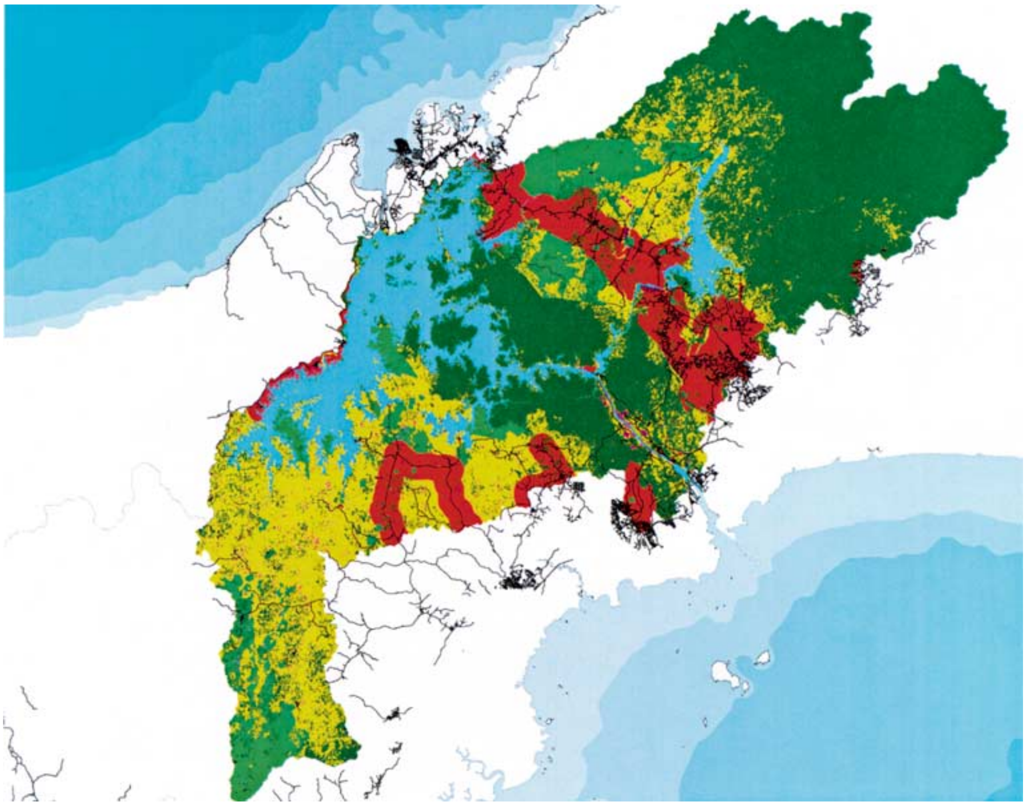

Figure 4. Continued.

land cover and C dynamics would decrease the uncertainty of the C emissions presented here.

The expansion and growth of plantations removes about 24,000 ha yr^{-1} initially to 205,000 ha yr^{-} at the end of the 20-year period (Figure 6). The C balance for the EPCW represents a net source of C to the atmosphere as the emissions from deforestation and conversion to agriculture/pasture/scrub lands exceeds the removals by the growing and expanding plantations. The business-as-usual scenario results in net C emissions of 606 thousand t C over the whole 20-year period.

Because of uncertainties in the C stock data, a series of simulations were run in which C stock estimates were varied by plus/minus the 95% confidence interval (CI) (Figure 7). Addition or subtraction of the 95% CI for all land cover classes increased or decreased the net emissions for the business-as-usual scenarios by +/–5% of emissions based on the mean C stocks. However, using a lower C stock (–95% CI) for native forests only decreased the net emissions by 72%. Clearly the C stock of native forest has a large impact on C emissions caused by land-cover change and indicates that improved accuracy and precision of the C of these forests is important for developing a more credible baseline.

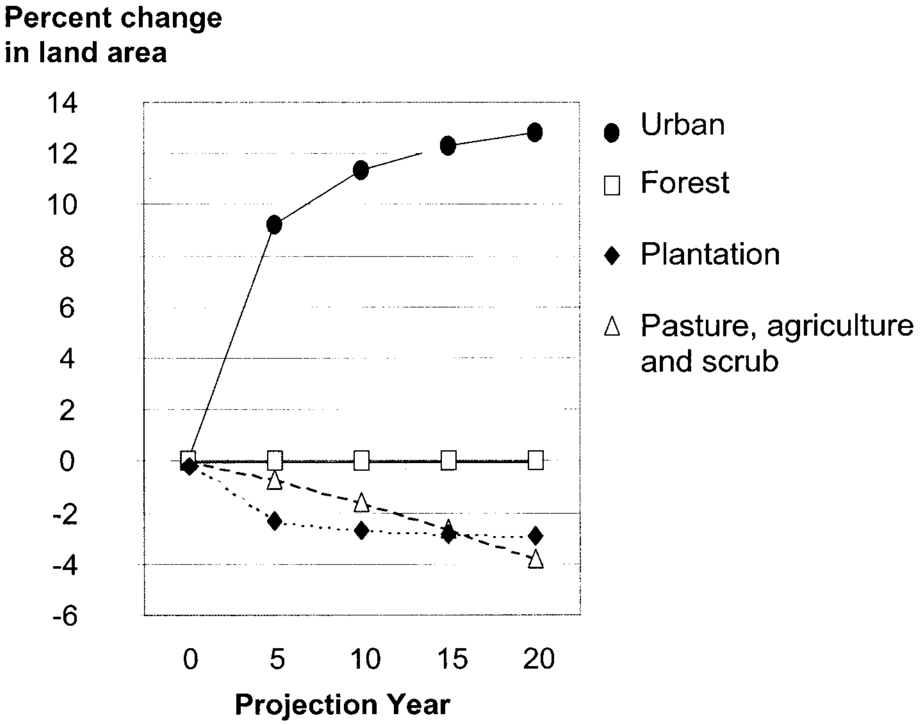

Figure 5. Change business-as-usual to new-road scenario for the major land cover categories in Panama.

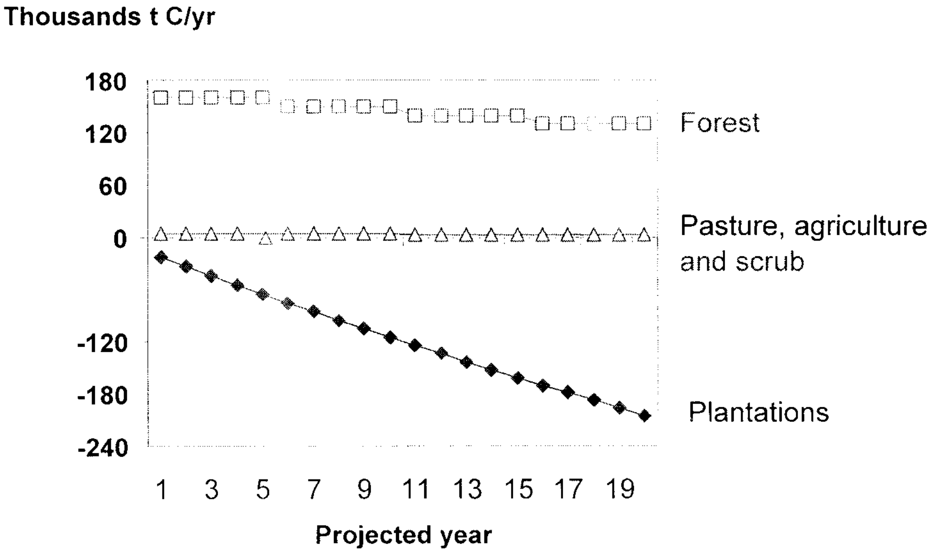

Figure 6. The Panama business-as-usual scenario net C emissions over 20 years.

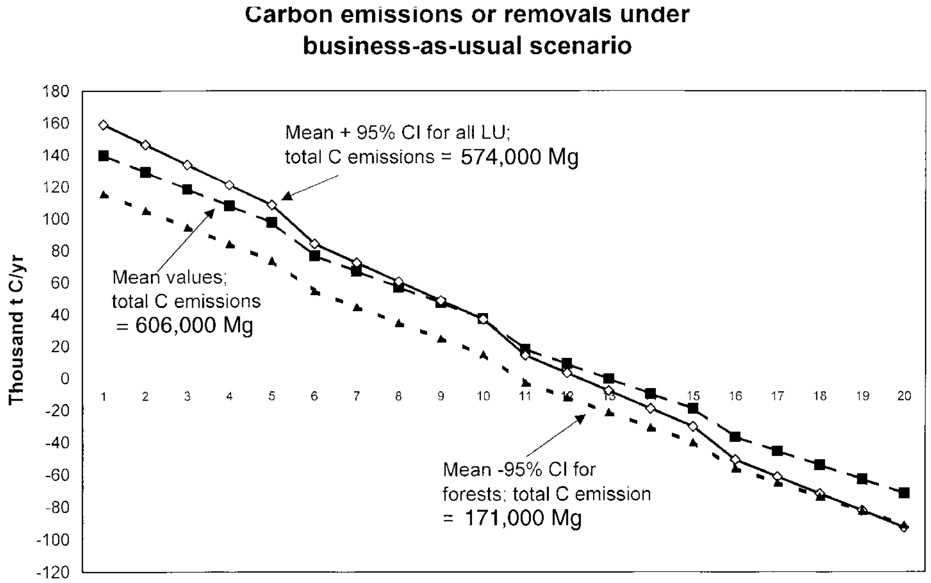

Figure 7. A series of simulations with C stock estimates varied by plus and minus their 95% confidence interval (CI).

The new-road scenario and the various assumptions for C densities resulted in higher net emissions of C (676,000 Mg C over the 20 year period) than the business-as-usual scenarios. The GHG emissions from deforestation for the new-road scenarios were only slightly higher than those for the business-as-usual scenarios; most of the increase in net emissions was caused by a reduction in the area converted to plantations.

4.3. IMPORTANCE OF SPATIAL REGIONAL PROJECTIONS

The projections that we have produced in this study not only tell how the use of land is changing and the corresponding changes in C stocks, but they also depict where these changes are occurring in the EPCW. The spatial aspect of the study provides several advantages in relation to actions needed to address GHG emissions and climate change, as well as other environmental concerns:

- With respect to national accounting of potential GHG emissions and removals into the future, this study aids in identifying the magnitude and location of the emissions and removals due to changes in the use and management of the land for this region. Under both business-as-usual and new-road scenarios, the EPCW is projected to be a net C source (emissions exceed removals) for the next 14 years or so, after which removals are projected to exceed emissions and become a C sink. This approach thus helps a country identify its potential

GHG liabilities into the future and provides opportunity for the country to plan alternative development pathways. Extending this analysis to the whole country, or at least to other regions undergoing rapid land-use change, would increase this knowledge base even further.

- With respect to land-use or forestry projects designed to generate C benefits, the results from the spatial baseline could be used by potential project developers to identify which types of projects will generate the largest C benefits, and at the same time provide the needed baseline against which a project is then evaluated (C benefits are the difference between with-project case and without-project or baseline case). The availability of this information would reduce transaction costs for project developers and make the EPCW a more attractive place for implementing such projects.
- A key aspect of the CDM is that projects related to reducing C emissions or increasing C removals must lead to sustainable development in the host country. Spatial baselines, such as presented here, can be used by governments to help identify development goals. Criteria used in evaluating sustainable development goals might include native forest conservation, increase in commercial timber production, conservation of soil and water resources, and conservation of biodiversity. These criteria can then be used by governments to encourage C projects that meet sustainable development goals.
- Although the market in C trading exists, the number of trades is relatively few. However, this market is likely to increase in the not-too-distant future, as countries that have taken on reduction targets attempt to meet their goals by the first commitment period (2008–2012). The development of such a baseline as presented here, and its expansion to other vulnerable areas, well positions Panama to respond to the future market demand for C offsets.
- It is useful to compare the projected change in land cover under the business-as-usual scenario to the goals set by Law 21 for the year 2020. The model projects that more urban areas will be created than called for by the Law. In other words, if current activities continue (as set forth in the model), then the urban area will exceed the area set by Law 21. Thus, a reconsideration of current practices should be conducted in order to evaluate how best to meet the goals for urban land that are stated in Law 21.

4.4. IMPROVEMENTS TO MODELING APPROACH

This study has greatly advanced knowledge and understanding of how future trends in development of the EPCW will influence land-use and land-cover changes and the resulting changes in C stocks. It has also brought to light several areas of needed improvement in the underlying data that could make this baseline more credible:

- The pattern of net changes in C stocks is very sensitive to the amount of C in native forests. The advantage of a spatial model is that it can match where the land use or land cover is changing with the C densities of the forests undergoing change. Of particular importance is the land-use and C dynamics of secondary forests, and further attention needs to be given to identifying the spatial distribution of different age forests and, thus, C density classes of these forest types. Also, more information is needed on the distribution of mature forests with potentially different C densities and that are also at high risk of land-cover conversion.

- The expansion and growth of plantations are also an important component of this study. We assumed only one rate of C accumulation and did not model any management practices, such as thinning, site preparation, or different rotation lengths. More data on the actual expected rates of C accumulation under a variety of expected management regimes across the region are needed. Rates of C accumulation for different mixes of plantation species, including natives and nonnatives, are also needed.
- Soil C gains (under reforestation with natural regeneration or plantations) or losses (from conversion of forests to agriculture) were not included in this analysis because of lack of key data. Improvements in data on rates of C accumulation or loss under different land-use practices are needed.
- In this study, we assumed that all plantations established would be successful and would continue to accumulate C over the 20-year period. However, this assumption may not always be the case, and there may be differences between small and large landowners in the success of their plantation endeavors. Further study of this topic is needed.
- Conducting a sensitivity analysis would provide a means to determine the greatest sources of variability in the land-use and C-stock projections. Although we discuss the implications of different initial C stocks on projected C flux, a formal sensitivity analysis would allow quantitative determination of the sources of greatest variability in the model.
- Changes in land use and C stock could be projected for longer or shorter time periods. For example, it might be useful to focus on the next decade as policies have an effect and changes to those policies occur.
- The approach allows for consideration of other ecological implications and feedback effects of projected changes in land cover. The decline in forest area and increases of land in urban, plantations, pasture, agriculture, and scrub areas may affect erosion; sediment deposition; biodiversity; and habitat quality, quantity, and pattern. The spatially-explicit projections of land-cover changes allow these other ecological impacts to be explored.

5. Conclusions

The small changes to forested land result in the largest source of C emissions in the EPCW. Thus, the most effective way to reduce C emissions is by reducing deforestation. The effect of forest removal is large because about half of the biomass in trees is C. Loss of mature forests contributes more to C emissions to the atmosphere than does the loss of secondary forest because mature forests typically contain many large trees and more C than trees that are smaller in size which dominate secondary forests (Brown and Lugo 1992; Brown et al. 1997). Under the current framework of the CDM, only C benefits arising from reforestation are allowed. However, as the CDM and other parts of the UNFCCC Kyoto Protocol are still under debate in political arenas, it is likely that the allowable activities for C benefits may change.

Even after 20 years, C gained by reforestation in the EPCW is not enough to offset the C emissions from the ongoing small rate of deforestation. The up-to 20 years of growth and C accumulation in the plantations is not enough to offset the high C stocks of established forests that are lost with their removal. However, planting larger areas to plantations than occurs in the business-as-usual scenario would cause more C to be stored.

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