POTENTIAL CHANGES IN ECOSYSTEM SERVICES FROM LAND USE POLICY IN PUERTO RICO

by

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Abstract

Ecosystem services are self- evidently important to society as natural capital inputs into economic markets, the basis for life-support systems such as clean air, clean water, and climate control, and are integral to quality of life issues. These services provided by communities of living organisms in their natural environment are, in some instances, invaluable and irreplaceable. Conservation planners must focus on ecosystem services as conservation priorities and target levels of ecosystem services as conservation goals, in order to manage and conserve these beneficial services. This paper explores 1) how Puerto Rico's draft national land use plan changes the environment's capacity to provide ecosystem services and 2) the limitations to describing ecosystem services and values.

The modeled losses in ecosystem service provision that occur with policy implementation support that ecosystem service conservation is not a goal of the draft land use plan. Limitations of modeling and mapping services likely inhibit policy consideration of ecosystem services, as do the limitations of describing numeric output of models, where they exist. Yet, qualitative outputs from the models provide useful information to policy makers about how land use policies will affect ecosystem services. This study is useful for future projects that wish to utilize ecosystem service mapping and valuation to review policy decision.

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Abbreviations

CCX	Chicago Climate Exchange
DNER	Department of Natural and Environmental Resources
EU ETS	European Union Greenhouse Gas Emission Trading Scheme
GDP	gross domestic product
GIS	Geographic Information System
GNP	gross national product
Gt C	gigaton of carbon
Ha	hectares
mT C	metric tons of carbon
Mt C	million tons of carbon
NOAA	National Oceanographic and Atmospheric Administration

I. Introduction

Ecosystem services are undoubtedly affected by human land use conversions and natural resource consumption. Large-scale environmental degradation and resource depletion are often coupled with land use decisions at the individual level. Yet, the large scope of ecosystem services (such as watersheds or mountain ranges) requires organized land use policy at a larger scale than individual land-owners and community-based organizations. Accordingly, national land use policies have recently become an integral component of ecosystem-based management and ecosystem service conservation.

Land use policies are further necessitated by rapid land use conversions caused by agricultural expansion or urban development. The duality of urban development is that it encroaches upon forested areas and previously cultivated lands. As lands suitable for agriculture become developed and thus scarcer, deforestation pressures from agricultural expansion increase as well.

The Caribbean has a long history of intensive agriculture. In the first half of the 20th century, Puerto Rico operated on an agrarian economy. The effects of intensive agriculture peaked in the 1940s, when forest cover was reduced to 6% across the island (Lopez and Thomlinson 2001). In the second half of the century, Puerto Rico shifted toward an industry-based economy and experienced the highest reforestation rates of any tropical country (Grau et al. 2004). Forest cover increased 62% between 1937 and 1995 (Pascarella et al. 2004).

Despite these improvements, population density is exacerbating issues of land demand. Puerto Rico is currently one of the world's most densely populated regions (Lopez and Thomlinson 2001). In Puerto Rico, the population density has reached a critical mass of 446 people km^2, making this island one of the most populated territories on the planet. Ironically, with a total land area of approximately 8,900 km^2, Puerto Rico is the smallest and most outer island of the Greater Antilles.

While small in size, Puerto Rico is home to a wealth of biological diversity in terrestrial, freshwater, and coastal marine environments. Its complex topography, soil composition, and numerous ecological zones create high rates of endemism (Helmer 2002). Unfortunately, much of that diversity is threatened by a burgeoning human populations and changes in land and resource use. Less than 5% of Puerto Rico's forests are protected; additionally the reserve system does not adequately represent many unique ecosystems (Helmer 2002).

These threats have not been ignored. In response to the exponential modernization and industrialization of the late 1960s, the government of Puerto Rico created several environmental agencies, including the Department of Natural and Environmental Resources (DNER) and the Puerto Rico Environmental Quality Board. The governments of Puerto Rico and the United States recognized the role of land use in conservation planning. They subsequently founded the Conservation Trust of Puerto Rico (Conservation Trust). The Conservation Trust is a private, non-profit institution dedicated to protecting Puerto Rico's environmental resources through land acquisition. The Conservation Trust is funded by federal money and private financial transactions, in addition to charitable land and monetary donations.

The DNER of Puerto Rico will have legal control of the island's land use policy for the next ten years and is currently finalizing a draft national land use plan. The Conservation Trust is concurrently requesting a partnership of conservation organizations and agencies to develop tools that prioritize areas of Puerto Rico for biodiversity conservation. These tools will be used to either assist the Planning Board of the DNER in development of the final land use plan or to reveal problems with the plan that may be rectified.

Such tools are useful for allocating life-sustaining resources as well as biodiversity, as evinced by the Millennium Ecosystem Assessment and the Natural Capital Project. Specifically, spatial tools for mapping and quantifying ecosystem services are becoming increasingly recognized. Five years ago, one editorial identified maps of ecosystem services as "virtually nonexistent" but crucial to illustrating key issues such as service provision under alternative land use management regimes (Balvanera et al. 2001). The major contribution of spatial tools is to elucidate the economic values of such services, specifically the social benefits and costs. This information can be useful to policy makers at multiple scales.

The focus of this paper is to 1) contribute our understanding of how well we can model land use policy effects on ecosystem services and 2) identify the limitations to quantifying ecosystem services and their values. I also draw conclusions for how well land use policy is accounting for ecosystem services.

I use Puerto Rico's current confidential draft land use plan as the land use policy example and then model net changes in the distribution of ecosystem services in Puerto Rico as a result of the plan. These services are a function of current land uses and will certainly be affected by any policy changes in future land uses. Consequently, the distribution of ecosystem service benefits throughout the Commonwealth of Puerto Rico will also change. This project will serve to inform policymakers of the potential environmental impacts and social welfare changes which may result from their policy decisions.

The framework for this spatial analysis is derived from peer-reviewed methods and available valuation studies. The approach compliments conservation valuation studies conducted by NatureServe and other benefits transfer studies relevant to the ecosystem services addressed in this paper.

This paper briefly reviews the state of the art of ecosystem service mapping and valuation. Second, it describes the linkages and decision framework for mapping services and their values. Third, the paper describes how to apply this framework to assess current land use conditions and changes in ecosystem services resulting from future land use policy in Puerto Rico. Fourth, this paper discusses the limitations and the extent to which ecosystem services can be spatially modeled. The paper concludes with comments on the contribution these studies make to future progress in quantifying ecosystem services.

II. Ecosystem services in this study

Carbon storage is a valuable ecosystem service that provides social benefits from intact ecosystems or creates social costs when ecosystems are degraded. This service slows the rate of atmospheric carbon dioxide accumulation and commensurate climate changes which result from global warming.

The atmospheric concentration of carbon has increased almost 30% over the last two centuries (Matthews et al. 2000). Land use change and fossil fuel combustion are the two main contributors to the increase. Deforestation and cultivation of grasslands have contributed a net increase of 137 (± 55) GtC CO2 emissions during that time, 119 and 24 GtC respectively (Houghton, 1999; Houghton et al., 1999; Houghton et al., 2000 *cited in* Matthews et al. 2000).

In Puerto Rico, agricultural lands are gradually becoming reforested, but urbanization and modernization of the island are resulting in increased carbon output (DNER 1996). Puerto Rico's carbon emissions per capita have increased 22% in the last 25 years (EIA 2006). The environment's capacity to offset the island's carbon emissions will become increasing important as the United States moves closer to a carbon tax or CO_2 regulations. Also, the environment's capacity to sequester carbon will become more valuable as the international carbon market becomes more developed.

III. The art of mapping and valuating ecosystem services

Allocating resources and identifying appropriate trade-offs is the essence of economics. As the human population increases and the environmental impacts of the population intensifies, economics must address ways to efficiently allocate environmental goods and services. It is difficult to design efficient economic markets or public policy around such issues without understanding trade-offs between benefits and costs.

Ecosystem services are emerging as a new paradigm for decision making because there are often tangible alternatives (e.g. water purification) with quantifiable costs. There are current efforts toward a global appraisal of ecosystem potential, such as the Millennium Ecosystem Assessment. These appraisals are best done in a spatial context, given that the distribution of ecosystem potential (i.e. goods and services) is essential to how they are evaluated for trade-offs.

Spatial descriptions of ecosystem services are beginning to include values, as well. The most progressive studies bundled ecosystem services and include those by Chan et al. 2006; Troy and Wilson 2006; and Hao et al. 2005. Other studies used GIS to map marginal benefits of environmental services to property values (Lake et al.2000; Bateman et al. 2000). There are intrinsic trade-offs in selecting a general versus specific model. Drawing on lessons learned, I will attempt to address the practical challenges associated with ecosystem service mapping and valuation using these progressive modeling approaches.

IV. Decision framework for mapping and valuing services

This framework is a synthesis of the most progressive research bring done in the areas of ecosystem service mapping, spatial valuation, and value transfer methods. This paper’s approach is based on Troy and Wilson 2006 and consists of the following: 4.1) define the spatial extent of the study area; 4.2) develop a comprehensive database of spatial characteristics that describe ecosystems; 4.3) scope the literature for mapping methods and value coefficients for spatial characteristics; 4.4) map the spatial landscape characteristics and relevant ecosystem service elements; 4.5) calculate values associated with elements; and 4.6) map ecosystem service values. The subsequent paragraphs indulge a general description of the steps. The application of these steps to this research is described in the next section.

A. Define the study area

Political boundaries do not often correspond to the physical boundaries of ecosystem service flows. Yet, both boundaries determine the selection of ecosystem services included in a study. Political and physical boundaries are also imperfectly overlapped by market boundaries. The end result is that these boundaries can significantly impact ecosystem services modeled and the economic values of ecosystem services in a study (Troy and Wilson 2006).

B. Spatial typology development

Ecosystem services are an undisputed function of landscapes. Once a study extent is defined, a spatial topology provides a simple way to describe the multitude of ecological landscape characteristics that provide services within the study extent. The typology relates a variety of landscape characteristics into smaller clusters by shared characteristics (e.g. water quality attributes, erosion potential factors). To create a topology, it is important to survey available spatial data for the study area. This is also a pertinent time to survey valuation studies that may have been conducted for specific environmental characteristics (e.g. coral types, species diversity) or the study area. The survey is a useful way to scope for required spatial data layers to support the valuation studies and identify information gaps.

C. Scoping literature for ES mapping methods and valuation

A literature review is a formal way to organize the search for 1) spatial studies conducted in the area, 2) methods for ecosystem service mapping, and 3) valuation coefficients for services associated with the spatial typology.

The goal, from a mapping perspective, is to adopt the most progressive methods for modeling the spatial distribution of ecosystem services. For valuation, the goal of a literature review is to obtain statistically valid valuation coefficients for each characteristic in the topology and, ideally, a deterministic way to weight them against each other.

Often, valuation studies are non-existent at a site and it is too costly to contract a new empirical study. The alternative is a benefit transfer, which is "application of data from a study site to a policy site" (Rosenberger and Loomis, 2001). The study site is the location of some existing benefits estimation study conducted from data for that site. The policy site is the site of interest for a new economic analysis, for which we have little or no valuation data.

This transfer option invites uncertainty and accuracy errors, but it is becoming increasing popular for its ability to fill information gaps where and provide a range of value estimates for a given service (Bateman 1999; Troy and Wilson 2006).

D. Mapping the distribution of ES

This step begins the synthesis of the data layers and values gleaned from the literature review. The importance of this step is often underappreciated, given the wide-spread use of user-friendly GIS software. This step determines the accuracy of the analysis based on available data, precision of the analysis in the form of data resolution, and, most importantly, the minimum mapping units. It is important to note the inevitable trade-offs between high resolution and large scale data layers. Troy and Wilson 2006 mention that data may be highly relevant but poor quality or, conversely, redundant but of high quality. The step is essential to making decisions about what data to keep, omit, combine, or update.

Mapping policy scenarios requires the inclusion of relevant spatial data, which may be difficult to ascertain and obtain. A single policy can affect a landscape differently at different scales; it is important to make these scale decisions during the mapping process by choosing an appropriate scale and mapping units.

E. Total value calculation

The mapping process above assigns environmental attributes to individual mapping units (such as pixels or parcels). In this step, those mapping units are assigned value coefficients associated with the attributes. These value co-efficients come from the literature review.

When the mapping units are translated into ecosystem service flows, the values can be summed by ecosystem service or corresponding attribute. Some methods suggest that the total value of service flows for a given attribute, specifically land cover, can be calculated by summing “individual, non-substitutable” service values associate with the attribute and then multiplying by the per unit area for ecosystem service type (Troy and Wilson 2006). Other studies use statistical methods, such as regression analyses, or mathematical computations to describe the relationship between attributes that create a service. The results of these methods do not employ a multiplier for value, but instead assign ecosystem value as a function of the ecosystem attributes (Hao et al. 2005; González-Cabán and Loomis 1999).

F. Map ecosystem service values

This step moves away from economic valuation and back into the spatial context of service flows. The purpose of this step is to view possible spatial landscape patterns of ecosystem service values (e.g. values a distance from city centers).

V. Puerto Rico application

A. Puerto Rico study area

The island of Puerto Rico is home to 2,891 native vascular plant species and 206 native vertebrate species- 106 avian species, 21 mammal species, 79 reptile and amphibian species. At the same time, the island is also home to one of the largest population densities in the world.

In addition to running surface water, karst streams, and groundwater, there is a natural lake (Lago Cartagena), coastal lagoons, natural ponds, and geothermal springs. Surface water flows are affected by island biogeography influences rainfall patterns and the impact of storm systems. Biogeography also affects turbidity via erosion potentials and chemical concentrations within the water column. Increased turbidity and degraded water quality in lower watersheds are exacerbated by human land and resource use.

Though Puerto Rico is at a latitude of 18^o N, it is classified in the “subtropical latitudinal region (Ewel and Whitmore 1973). According to the Holdridge Life Zone concept (1940), there are six climate-based terrestrial life zones on Puerto Rico ranging from rain forests to dry forests at sea level; wet forests to rain forests in the lower mountainous areas.

Table 1. Terrestrial Life Zones according to Holdridge’ s Life Zone concept.

Life Zone	**Area**
Percent of total Area	93.72
Subtropical Dry Forest	1216.4
Subtropical Moist Forest	5326.1
Subtropical Wet Forest	224.8
Subtropical Rain Forest	13.2
Subtropical Lower Montane Wet Forest	109.1
Subtropical Lower Montane Rain Forest	12.3
Total Area	8801.9

The NE trade winds and islands biogeography create moist windward conditions along a gradient from the NE to the southwest. The climatic patterns and heterogeneous topography create 28 climatic zones. Similar areas include much of the Greater Antilles and Central America, Southeast Asia, and islands from the western Pacific to the Indian Ocean (USGS 2000).

B. Typology development

I defined the geographic study extent as the waters and coral surrounding the island. For each ecological landscape within this extent, I began surveying the spatial data for the island and surrounding corals.

National Oceanographic and Atmospheric Administration (NOAA) Summit to Sea analysis of Puerto Rico provided a nearly complete database of watershed basins, bathymetry, soil quality, slope, erosion, precipitation, and coral reef threats. In addition, NatureServe's database included most spatial data for the geographic, biological, and climatic attributes. Most important was a spatial land use dataset for the current baseline conditions and land use dataset for conditions under the draft plan, created by NatureServe.

I was unable to find any carbon studies specific to Puerto Rico. The Matthews et al. 2000 study provided the overview for carbon storage values for four ecosystem types. This prompted the search for Puerto Rico forest ecosystem data at a level of precision comparable to ecosystems described in the paper.

C. Scoping literature for ES mapping methods and valuation

I conducted a literature review to organize the search for 1) spatial ecosystem service studies conducted in the area, 2) methods for ecosystem service mapping, and 3) valuation coefficients for ecosystem services.

1. *Spatial ecosystem service studies conducted in the area*

As mentioned, there have been a number of spatial databases created for Puerto Rico. In addition to the existing biodiversity work being done by

NatureServe, NOAA recently completed the Summit to Sea watershed study. Its focus was coral reef threat and vulnerability as a function of terrestrial land use and erosion.

There have also been studies on recreation benefits from water quantity. The US Department of Agriculture (USDA) conducted a project which measured the economic benefits of ecological integrity and recreation in a watershed in Puerto Rico (González-Cabán and Loomis 1999). A sister study created a spatial model based on regressions within that paper. Their methods are similar to hedonic regression models mentioned above.

2. ***Methods for ecosystem service mapping***

Ecosystem service mapping methods were based on the most progressive papers in ecological economics and biology, as well as mapping projects conducted by academia and federal agencies.

Troy and Wilson 2006 provided an elegant way to design a decision support framework for conducting ecosystem service mapping and benefit transfers. Though this paper will not replicate the exact methods of Troy and Wilson, the structure is based on the framework provided in the paper.

Variations on methods by Chan et al. 2006, which will be further discussed later, were used to map carbon storage. Mapping these ecosystem services required a new data search for census data; carbon storage data at the appropriate scale and carbon storage coefficients.

3. *Valuation coefficients for ecosystem services*

There were certainly some information gaps and limitations on available valuation data. The limitations prompted a narrowing of ecosystem services targeted in this study.

A study on global carbon storage by Matthews et al. 2000 provided an estimated range for carbon storage capacity (tC/ ha) for ecosystem types (Table 2). The study also provided a map of global carbon storage values for countries around the world. This study did not put a market price on these values.

Table 2. Estimated Range of Total Carbon Storage Values by Ecosystem
from Matthews et al. 2000

Ecosystem Type	Total Land Area (106 km2)	Global Carbon Stocks (GtC) Vegetation (GtC)	Soils (GtC)	Total (GtC)	Carbon Stored/Area (t C /ha)
Forests Low latitude	12.8	48-265	131	180-396	140-310
Agriculture Low latitude	9.5	20-72	85	105-157	110-164
Grasslands Low latitude	21.7	40-126	158	197-284	91-131
Other Low latitude	8.8	4-16	34	38-50	43-56

The United States has not yet adopted a carbon tax, but the average 3- month mid-price of a carbon credit on the CCX, US $4.25[1], is often used as a lower estimate of the value of carbon storage for ecosystems in Puerto Rico. The average 3- month mid-price of a carbon credit on the EU ETS, US $11.30[2] can provide an upper estimate of the carbon storage ecosystem service values.

Yet, these values are significantly lower than the estimated marginal social cost of carbon. This is the monetary value of damages caused by emitting a ton of carbon (Pearce 2003). This value certainly depends on the social discount rate but estimates range from $4 to $50 tC, using discount rates from 3% to 5% (Tol and Downing 2000; Eyre et el. 1997). A study by Pearce (2003) is the most comprehensive meta-analysis of estimates of the marginal social cost of carbon.

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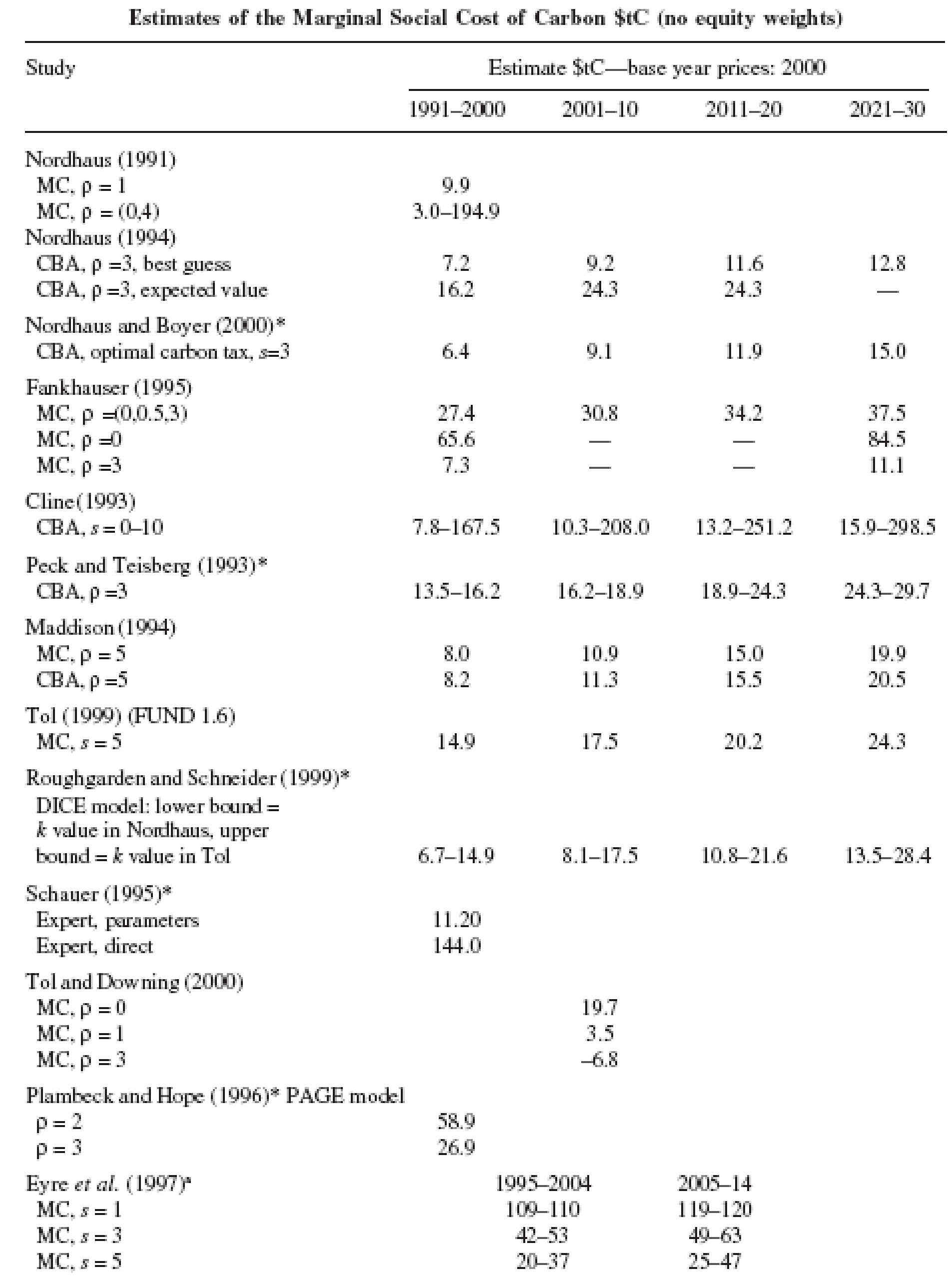
[1] From the Katoomba Groups's Ecosystem Marketplace.
[2] Ibid.

Table 3. Meta- analysis estimates of the marginal social cost of carbon *from Pearce 2003*.



Estimates of the Marginal Social Cost of Carbon $tC (no equity weights)

Study	Estimate $tC—base year prices: 2000			
	1991–2000	2001–10	2011–20	2021–30
Nordhaus (1991)				
MC, ρ = 1	9.9			
MC, ρ = (0,4)	3.0–194.9			
Nordhaus (1994)				
CBA, ρ =3, best guess	7.2	9.2	11.6	12.8
CBA, ρ =3, expected value	16.2	24.3	24.3	—
Nordhaus and Boyer (2000)*				
CBA, optimal carbon tax, *s*=3	6.4	9.1	11.9	15.0
Fankhauser (1995)				
MC, ρ =(0,0.5,3)	27.4	30.8	34.2	37.5
MC, ρ =0	65.6	—	—	84.5
MC, ρ =3	7.3	—	—	11.1
Cline(1993)				
CBA, *s* = 0–10	7.8–167.5	10.3–208.0	13.2–251.2	15.9–298.5
Peck and Teisberg (1993)*				
CBA, ρ =3	13.5–16.2	16.2–18.9	18.9–24.3	24.3–29.7
Maddison (1994)				
MC, ρ = 5	8.0	10.9	15.0	19.9
CBA, ρ =5	8.2	11.3	15.5	20.5
Tol (1999) (FUND 1.6)				
MC, *s* = 5	14.9	17.5	20.2	24.3
Roughgarden and Schneider (1999)*				
DICE model: lower bound = *k* value in Nordhaus, upper bound = *k* value in Tol	6.7–14.9	8.1–17.5	10.8–21.6	13.5–28.4
Schauer (1995)*				
Expert, parameters	11.20			
Expert, direct	144.0			
Tol and Downing (2000)				
MC, ρ = 0		19.7		
MC, ρ = 1		3.5		
MC, ρ = 3		–6.8		
Plambeck and Hope (1996)* PAGE model				
ρ = 2	58.9			
ρ = 3	26.9			
Eyre *et al.* (1997)*		1995–2004	2005–14	
MC, *s* = 1		109–110	119–120	
MC, *s* = 3		42–53	49–63	
MC, *s* = 5		20–37	25–47	

Pearce 2003 concludes that the social value of carbon ranges from $4- $9 tC (using a constant discount rate and without equity weighting), to $3.6– $22.5 tC. (using equity weighting).

The literature most commonly cites Fankhauser's (1994) estimate of $20 for the marginal social damage created by one ton of carbon (Adger et al.1994, Pearce 2003, Bateman 2000, Creedy 2001). Thus, society would be willing to pay up to $20 to remove that ton of carbon or prevent it from entering the atmosphere.

D. Mapping the baseline distribution of ecosystem services

Carbon storage is a function of ecosystem vegetations and soils. Mapping the distribution of carbon storage required a current land use map for Puerto Rico (for forest, agriculture, and urban type), baseline Helmer land cover map (type of ecosystem), and the carbon storage capacities for low latitude ecosystem types from the Matthews et al. 2000 study on global carbon storage.

I first created a Helmer land cover raster surface of 1ha (100m x 100m) cells to reflect the ecosystem in appropriate planning units. I then used the baseline land use classifications from NatureServe to remove developed areas that were unable to store carbon (Table 4). Areas such as "Unknown" were generously reclassified as being able to store carbon.

Table 4. Screening out developed land uses from Helmer land cover.

"Natural" Landscapes
Unknown
Biodiversity conservation
Natural area recreation and open space
Unknown specific working/occupied use
Low intensity working landscape
Low-density development
"Developed" Landscapes
Major road
Major highway
Unknown specific high intensity use
High intensity working landscape/recreation parks
General urbanization: homes, commercial, industrial, etc

The resulting data layer included 1 ha cells of different ecosystem types which are able to store carbon. I reclassified this remaining suitable land cover data into the four types of ecosystems described by the Matthews et al. 2000.

Table 5. Reclassifying the land cover into Matthews et al. 2000 ecosystem types.

Matthews et al. 2000 Ecosystem Type	Helmer Land Cover
Bare	Caribbean coastal rocky shore Caribbean coastal sandy beach Helmer Quarry Helmer Urban Salt Mining
Other	Caribbean coastal thorn scrub Caribbean edapho-xerophilous "mogote" complex Caribbean montane wet short shrubland Caribbean salt flats and ponds Caribbean serpentine dry scrub Helmer Water
Grasslands	Caribbean emergent herbaceous estuary Caribbean freshwater marsh
Agriculture	Coconut Palm Plantation Helmer Agriculture Helmer Agriculture/Hay Helmer Pasture Helmer Submontane and lower montane wet evergreen forest/shrub and active/abandoned shade coffee
Forest	Caribbean estuarine mangrove forest Caribbean floodplain forest Caribbean lowland dry semi-deciduous forest Caribbean lowland moist serpentine woodland Caribbean maritime shore/estuary mouth mangrove Caribbean montane wet elfin forest Caribbean montane wet serpentine woodland Caribbean montane/submontane karst forest Caribbean riparian forest and woodland Caribbean seasonal evergreen lowland forest Caribbean seasonal evergreen submontane/lowland forest Caribbean wet montane forest Caribbean wet submontane/lowland forest HelmerActive sun/shade coffee, submontane and lower montane wet forest/shrub

Total carbon (Mt C) was equal to the total area of each ecosystem type (ha) multiplied by the lower estimate of carbon stored/ area (t C/ ha) (Table 2). I then mapped the total carbon storage capacities for each municipality, using ESRI's ArcMap 9.2 Spatial Analyst to sum all 1 ha cells for the areas within each municipality. I also weighted this sum by its area to see which municipalities provide the most carbon storage capacity.

E. Mapping the policy scenario distribution of ecosystem services

Mapping the distribution of carbon storage required NatureServe's draft policy land use scenario map for Puerto Rico (same attributes as baseline conditions), baseline Helmer land cover map (same map as above), and the carbon storage capacities from the Matthews et al. 2000 (Table 2).

I created a draft policy land use raster surface of 1 ha (100m x 100m) cells and masked out developed areas. I reclassified the data in the same way as the baseline conditions using the lower range estimates of ecosystem storage capacity Matthews et al. 2000.

I used the ESRI ArcGIS 9.2 Spatial Analyst to calculate the change in carbon storage values from the baseline conditions to the policy conditions. In this tool, I subtracted the baseline conditions from the policy conditions so that the resulting data surface raster of 1 ha cells would represent the positive or negative change in storage capacity (tons/ ha) for each 1 ha cell. I also calculated the percent change in carbon storage capacity of each 1 ha cell across the island. Last, I computed the change in carbon storage ecosystem services from baseline to policy land use plans for each municipality.

F. Map ecosystem service values

I multiplied the baseline and policy carbon storage capacity for each ecosystem type (tC/ ha) from Matthews et al. 2000 times the social value of one ton of carbon ($US/ tC). I used the ESRI ArcGIS 9.2 ArcMap software to map the resulting raster baseline and policy dataset of the carbon storage value for each 1 ha cell across the island ($US/ ha). I also used ArcMap raster calculator to calculate the change and percent change in ecosystem service values from the baseline conditions to the policy conditions.

VI. Results

A. Mapping the baseline distribution of ecosystem services

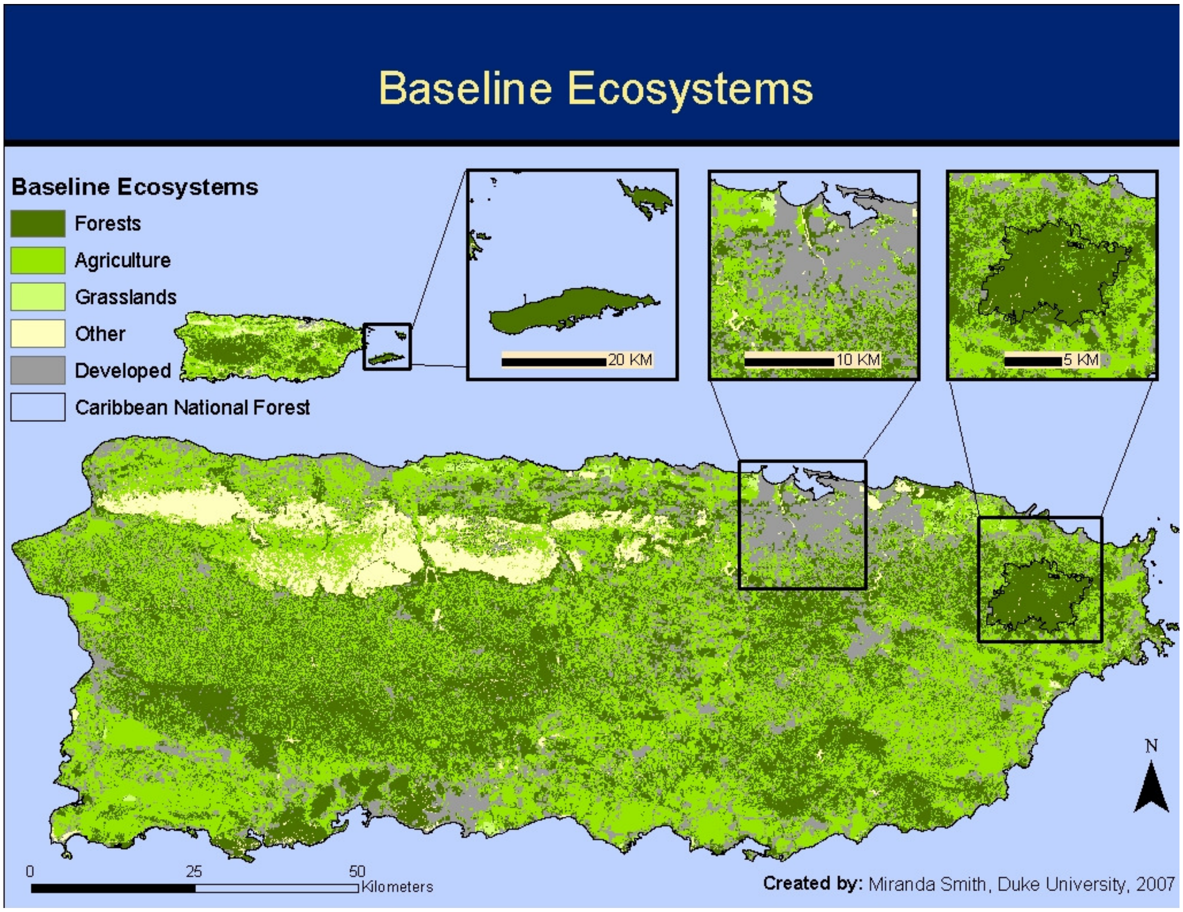
I mapped the baseline distribution of ecosystems, as defined by Mathews 2002 (forests, agricultural lands, grasslands, and other), without excluding developed areas. The current total carbon storage capacity in Puerto Rico, without masking out developed areas, was 94.92. The majority of carbon storage was attributed to forests because forest was also the dominant land cover type and it has the highest capacity to store carbon. The total area available for carbon storage in the model was 89, 3295 ha.

Table 6. Carbon storage capacity under baseline land use conditions, including developed areas.

Ecosystem Type	Carbon Stored/Area (t C /ha)	Total Carbon (Mt C)
Forests	140	49.66
Grasslands	91	0.28
Agriculture	110	42.76
Other	43	2.22
Bare	0	0.00
Sum		94.92

The baseline land use data provided by NatureServe enabled me to remove developed areas unsuitable for carbon storage. I then mapped the baseline distribution of ecosystems as defined by Mathews 2002, including forests, agricultural lands, grasslands, and other. The excluded areas are in grey.

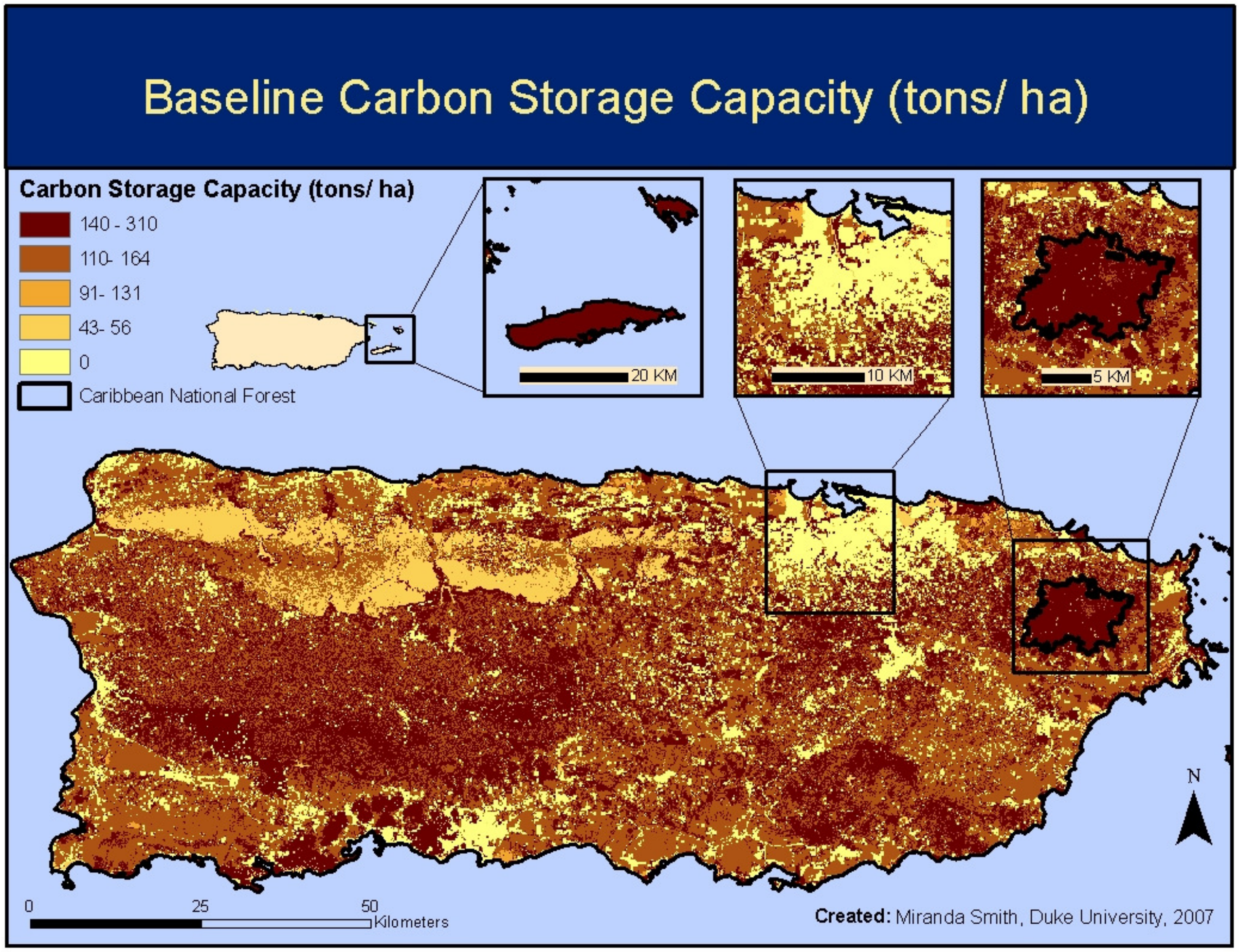
Figure 1. Baseline distribution of ecosystems across Puerto Rico



The map shows heavily forested areas in dark green, like the Caribbean National Forest on the right, and grey areas of high development, like around San Juan in the middle.

Then, using the WRI values for ecosystem carbon storage capacity, I mapped carbon storage capacity of ecosystems as a function of baseline land use conditions as well as land cover.

Figure 2. Baseline carbon storage capacity (Mt C/ ha) across Puerto Rico



The carbon storage capacities are ranges based on the Matthews et al. 2000 WRI estimates of high and low carbon storage capacity for each ecosystem type. Lighter areas have zero carbon storage capacity (tC/ ha) because they are developed areas, like areas around San Juan. The darkest areas are areas of forest, which sequester the most carbon per hectare, like the Caribbean National Forest.

The current total carbon storage capacity in Puerto Rico was modeled to be 89.49 Mt C (Table). In this model, agricultural land cover was the largest land cover type in area (ha), but the forests still sequestered the highest total amount of carbon. The total area of forest, when developed areas were excluded, was 37,497 ha less than the area of forest cover when land use was not included. The total difference in land area included in the model was only 524 hectares, but the amount of baseline land cover decreased by 38,935 ha when developed areas are excluded in the model.

Table 8. Carbon storage capacity under baseline conditions, excluding development.

Ecosystem Type	Carbon Stored/Area (t C /ha)	Total Carbon (Mt C)
Forests	140	46.27
Grasslands	91	0.56
Agriculture	110	45.42
Other	43	2.22
Bare	0	0.00
Sum		94.47

B. Mapping the policy scenario distribution of ecosystem services

I calculated the distribution of ecosystems and commensurate carbon sequestration capacity after the policy is implemented, excluding developed areas.

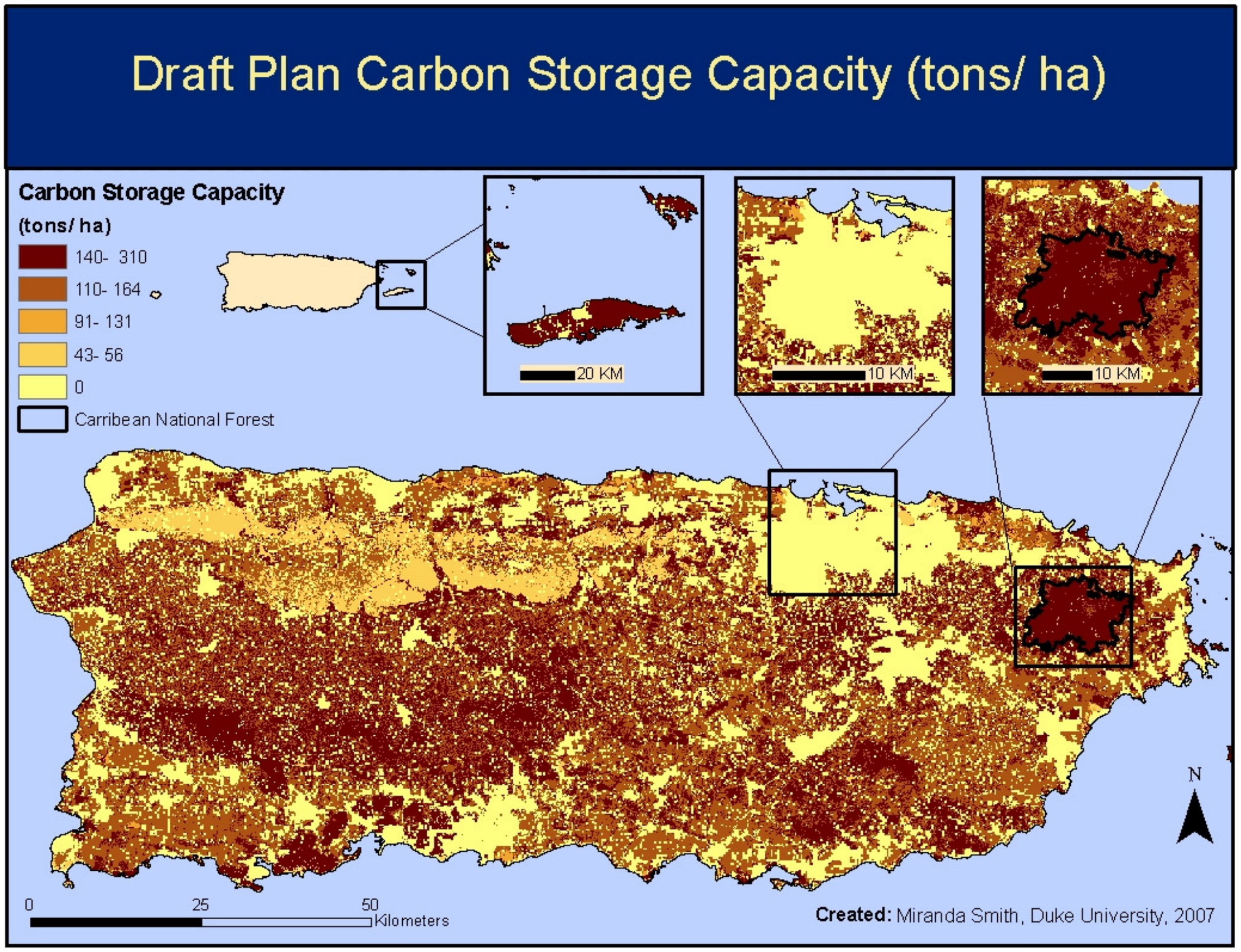
Total carbon storage capacity (tC) under the proposed land use plan was equal to the total area of each ecosystem (ha) multiplied by the Matthews et al. 2000 WRI estimate of carbon stored/ area (tC/ ha) (Table 2). The total carbon storage capacity in Puerto Rico under the draft plan was modeled to be 74.76Mt C. This capacity is 14.73 MtC less than the capacity under the baseline scenario.

Table 9. Carbon storage under the draft land use plan, excluding developed areas.

Ecosystem Type	Carbon Stored/Area (t C /ha)	Total Carbon (Mt C)
Forests	140	38.42
Grasslands	91	0.45
Agriculture	110	33.94
Other	43	1.96
Bare	0	0.00
Sum		74.76

I mapped out the raster dataset that was generated from this calculation of carbon storage capacity (Figure 3). These values represent the modeled range of carbon storage capacity across the island.

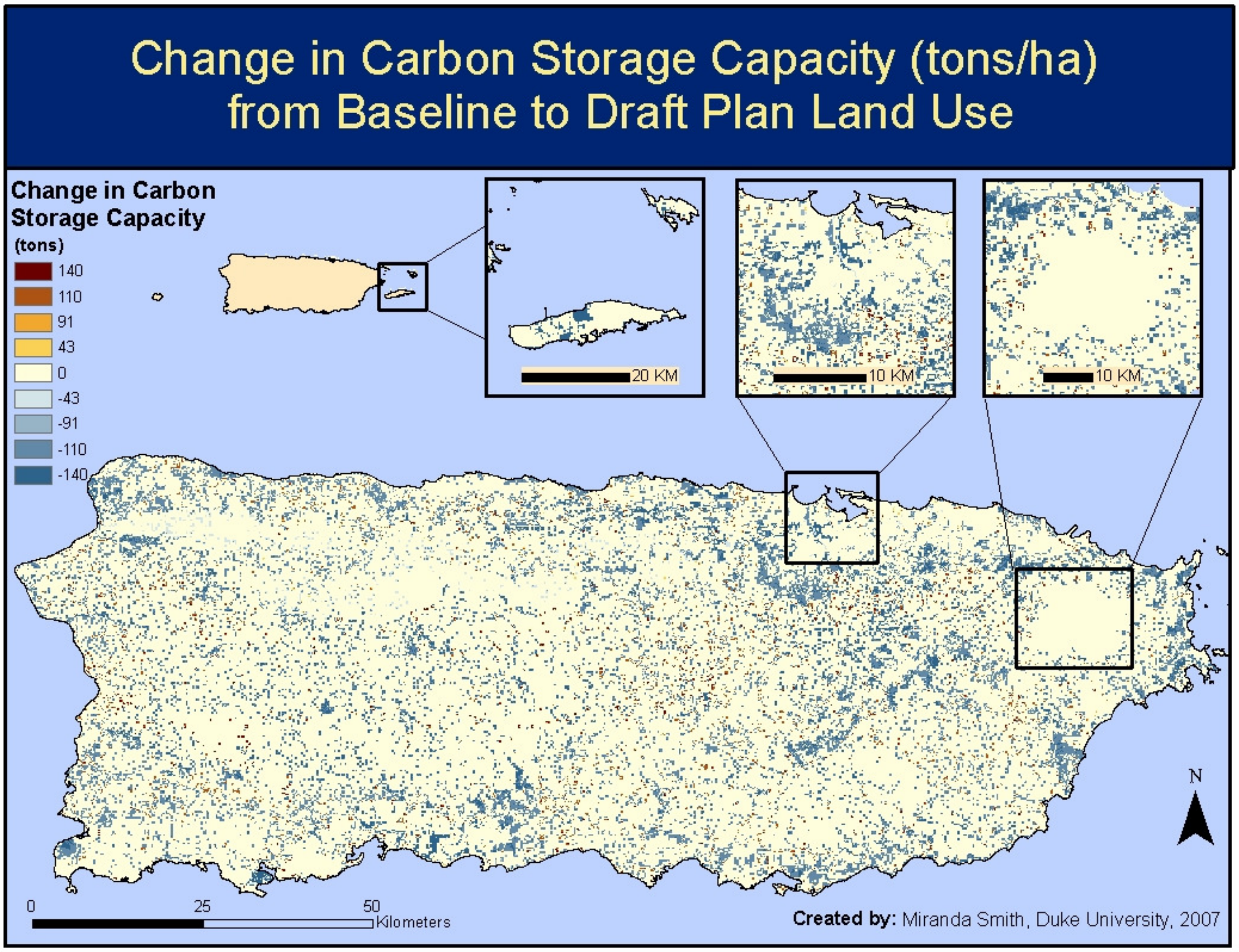
Figure 3. Draft plan carbon storage capacity (Mt C/ ha) across Puerto Rico.



The range of carbon storage capacity values reflect the range of carbon storage capacities estimated by WRI. The lighter areas have a lower carbon storage capacity (mT C/ ha) because they are developed. Darker areas, like the Caribbean National Forest, are more capable of storing carbon because they are forested.

There are numerous changes in carbon storage capacity across the island as land use policy shifts to the draft plan, ranging from isolated increases of 140 MtC to losses of 140 MtC (Figure 4).

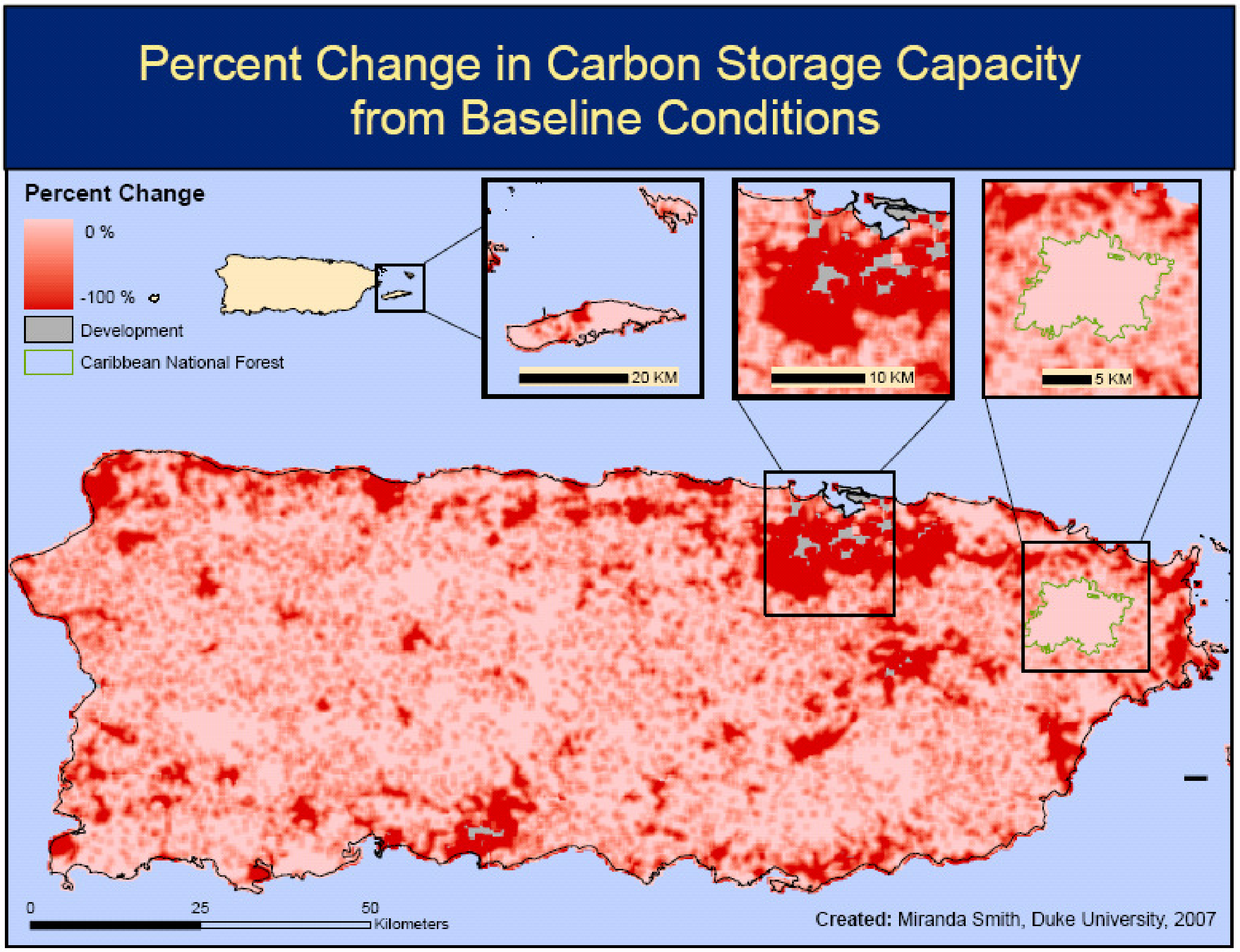
Figure 4. Change in carbon storage capacity (tC/ ha) across Puerto Rico.



A positive change means improved carbon storage capacity (such as reforestation), a negative change means lost capacity (such as deforestation or development). The Caribbean National Forest remains unscathed while areas around San Juan lose carbon storage capacity.

The percent change in ecosystem service capacity after the land use policy is implemented is one of the more interesting components of the comparison (Figure 5). These values were generated using ESRI ArcGIS raster calculator.

Figure 5. Percent change in carbon storage capacity across Puerto Rico.



A map of these percent changes, averaged over 1km, showed hotspots of negative percent change near coastal areas and near San Juan. Across the island, there was a total negative 16% change in total carbon storage capacity (14.73 Mt C) between the baseline land use (89.49 Mt C) and draft plan land use (79.76). The carbon storage capacity of forest ecosystems changed by negative 13% (6 Mt C), while grasslands experienced a negative 15% change in carbon storage capacity, though less than 1000 ha were affected by the land use plan. Agricultural lands undergo the largest percent change in carbon storage capacity, losing 20% of carbon storage capacity for this ecosystem. This change reflects a lost capacity of 169 Mt C across the island.

C. Total value calculation

The baseline carbon storage capacity in Puerto Rico was 95 Mt C, when developed areas were included. I multiplied this value of the total carbon stored (Mt C) by $20 social value of one ton of carbon.

The baseline social value of carbon storage capacity was $1.9 billion dollars, when developed areas were not excluded (Table 10). The majority of this value was from forest ecosystems, with agricultural contributions close behind.

Table 10. Carbon storage values under baseline conditions, including developed areas.

Ecosystem Type	Total Carbon (Mt C)	Social Value of Carbon ($US million)
Forests	49.66	925.41
Grasslands	0.56	11.15
Agriculture	42.76	908.47
Other	2.22	44.40
Bare	0.00	0.00
Sum	94.47	1889.44

When developed areas are excluded, the carbon storage capacity drops to 89.49 Mt C and is valued at $1.79 billion dollars (Table 11). The majority of sequestration is still occurring in forest ecosystems.

Table 11. Carbon storage values under baseline conditions, excluding developed areas.

Ecosystem Type	Total Carbon (Mt C)	Social Value of Carbon ($US million)
Forests	44.41	888.11
Grasslands	0.52	10.47
Agriculture	42.39	847.86
Other	2.17	43.31
Bare	0.00	0.00
Sum	89.49	1,789.75

Carbon storage capacity under the draft land use plan dropped to 74.76 Mt C. The social value of carbon storage under the draft plane decreases to $ 1.5 billion dollars - $294.5 million dollars less than the value of the baseline carbon storage capacity (Table 12).

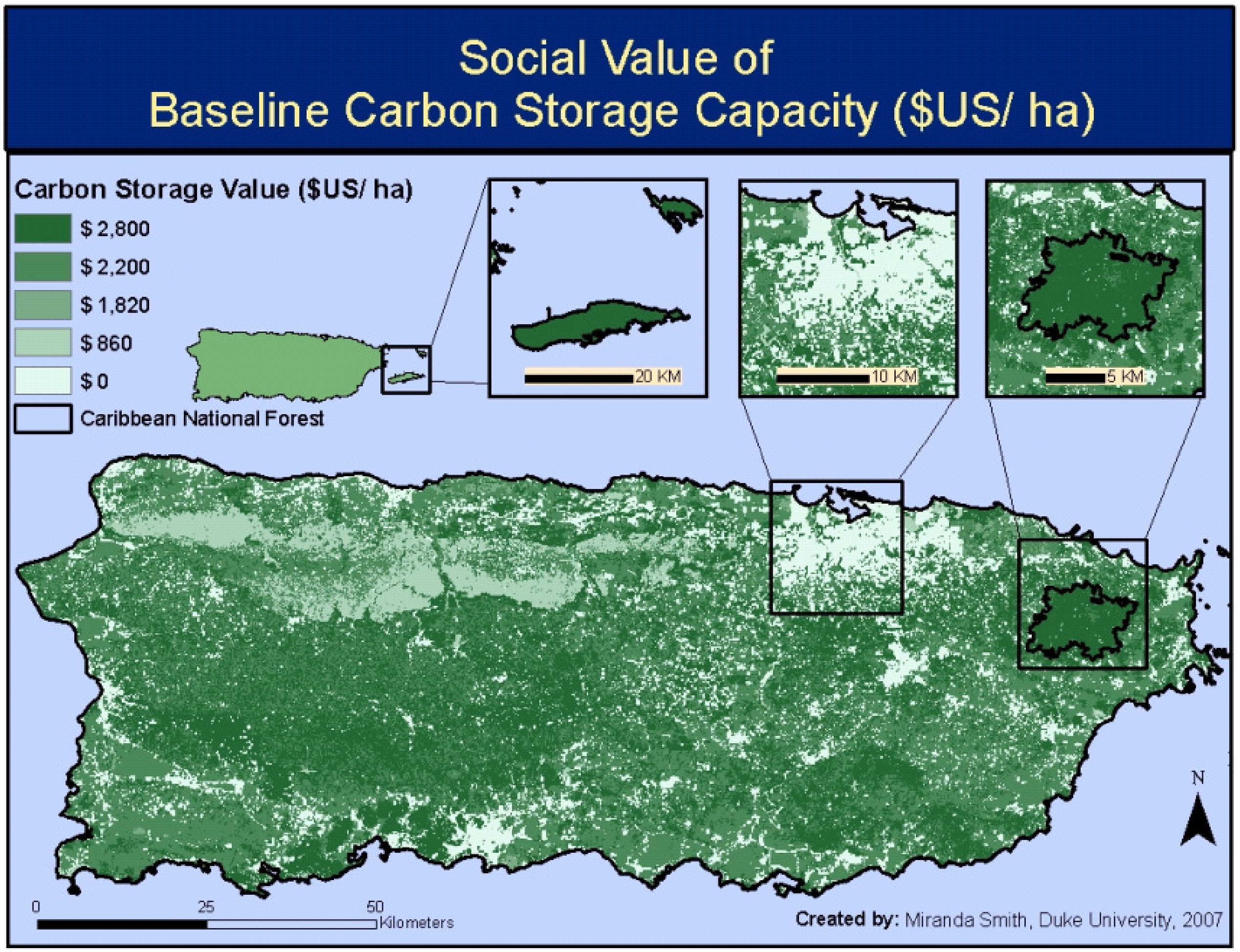
Table 12. Carbon storage values under the draft land use plan.

Ecosystem Type	Total Carbon (Mt C)	Social Value of Carbon ($US million)
Forests	38.42	768.39
Grasslands	0.45	8.92
Agriculture	33.94	678.71
Other	1.96	39.20
Bare	0.00	0.00
Sum	74.76	1495.22

D. Map ecosystem service values

The ecosystem service value calculations from above resulted in a raster dataset of ecosystem service values per hectare. I used ESRI ArcGIS to map this raster of the social value of baseline carbon storage capacity (Figure 6).

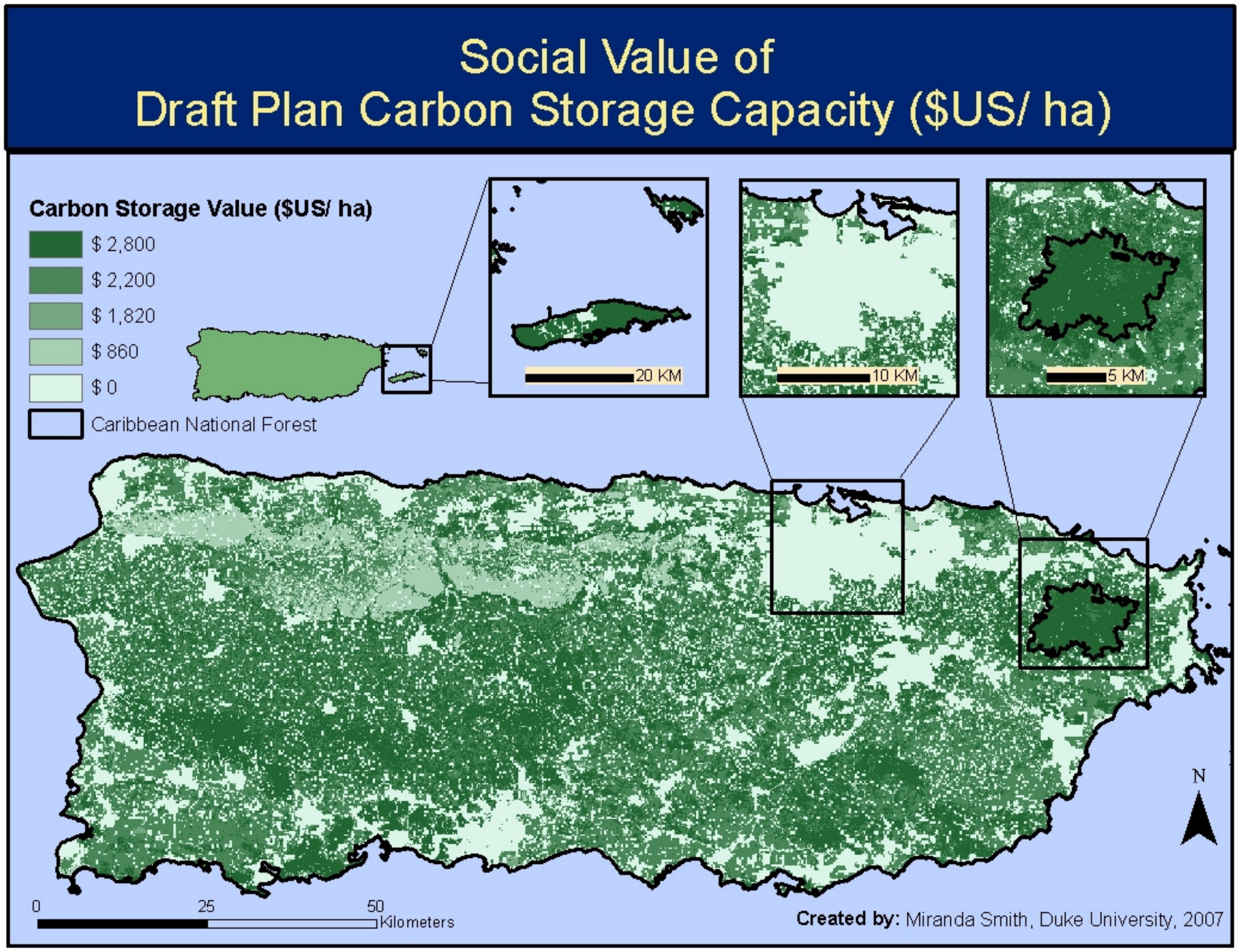
Figure 6. Social value of carbon storage ($US/ ha) under the baseline conditions.



Similar to the results for carbon storage capacity, lighter areas of the map have no social value with respect to carbon storage because they are developed areas and thus unable to sequester carbon, like areas around San Juan. The darkest areas are of the highest value, because they sequester the most carbon per hectare, like the Caribbean National Forest.

I also computed the social value of carbon storage capacity under the draft plan and created a raster dataset containing these values. I mapped out this raster for the island (Figure 7).

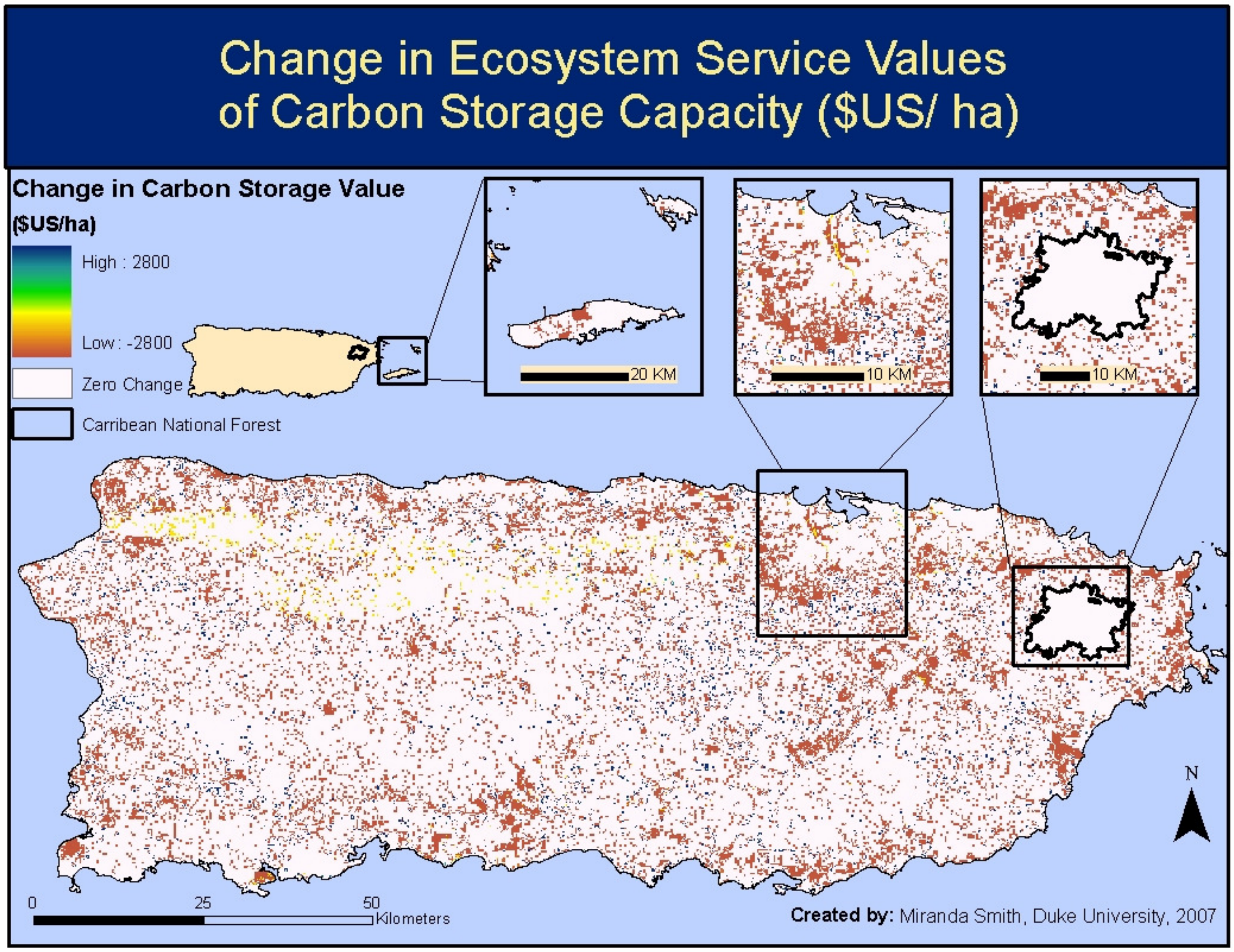
Figure 7. Social value of carbon storage capacity ($US/ ha) under the draft plan.



Areas around San Juan and the coast have appear lighter than they were under the baseline land use conditions because these areas have lost carbon storage capacity. The Caribbean National Forest appears to have retained its value with respect to carbon storage since the land use in these areas did not change under the plan.

Changes in the social values of carbon storage, as land use policy shifts from baseline conditions to policy conditions, are similar to the results for changes in carbon storage capacity (Figure 8).

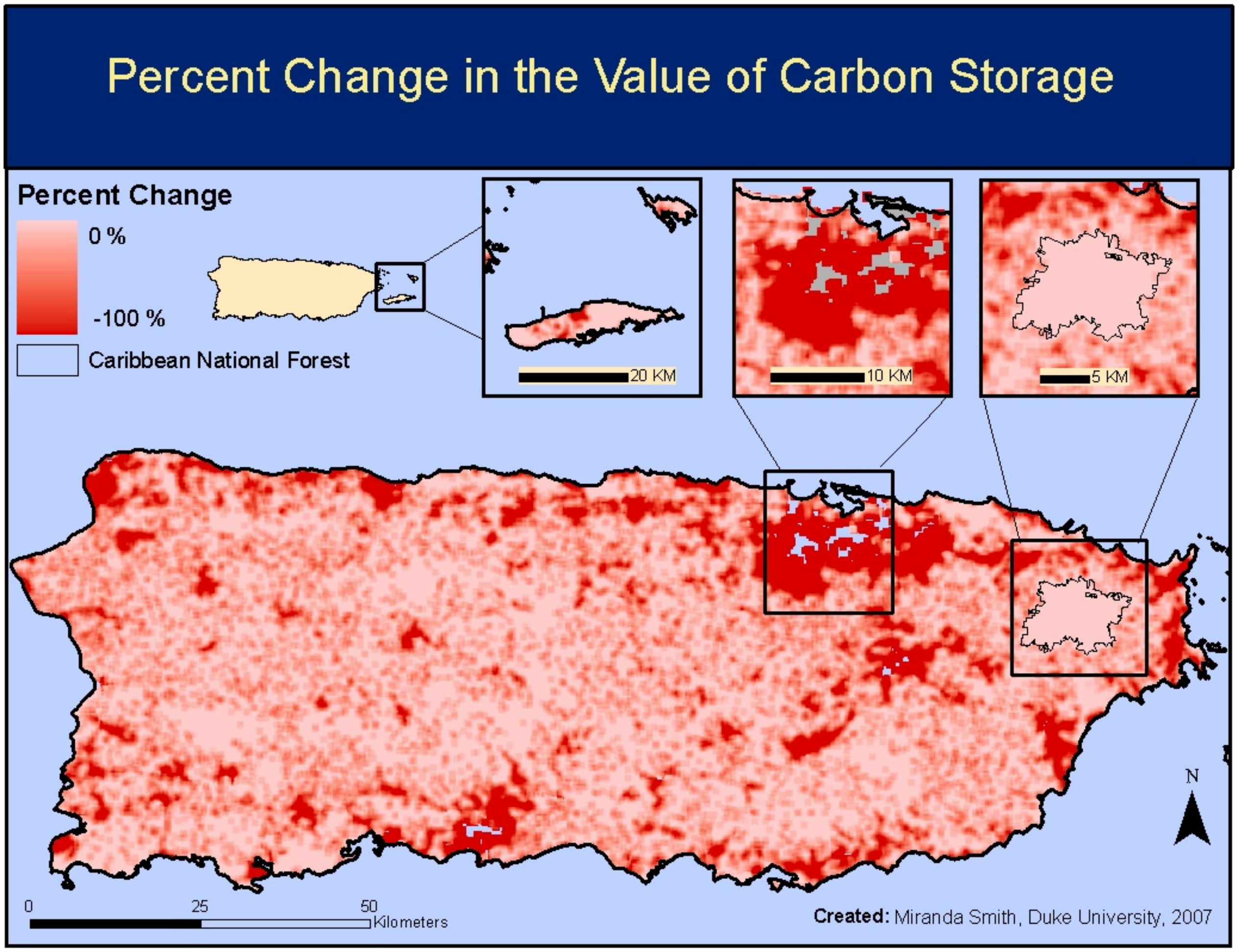
Figure 8. Change in social value of carbon storage capacity ($US/ ha).



Many areas experience no gains or losses in social value, because they experience no change in carbon storage capacity. Areas that have large negative changes (e.g. $2800 per hectare) are areas that lose the most valuable lands for carbon storage areas, like forests. There are concentrations of these large negative changes close to San Juan and in coastal areas.

Like percent changes in carbon storage capacity, percent changes in ecosystem service values after the land use policy is implemented is one of the more interesting components of the comparison and a useful output for policy makers (Figure 9).

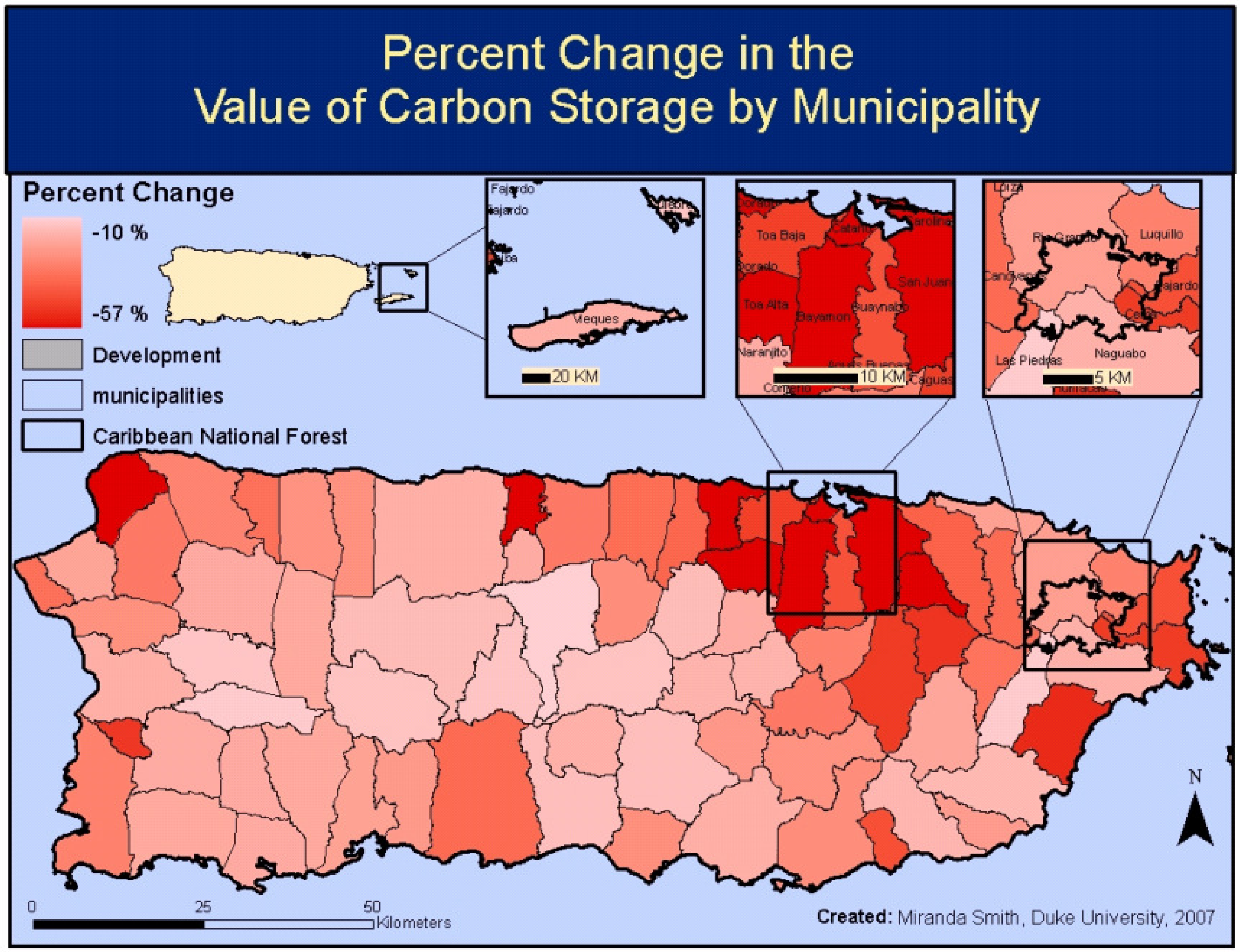
Figure 9. Percent change in social value of carbon storage capacity ($US/ ha).



There was a total negative 16% change in total carbon storage capacity and this negative 16% change also applies to the value of that capacity, since we are using a multiplier, not equation, to reflect the social value of carbon storage capacity. Similar to percent change in carbon storage capacity, there is a negative percent change in the value of carbon storage capacity across the entire island. Also, the effect of the land use plan across the island is not consistent; there are hotspots of large percent change (~100%) across the island, while some areas are unaffected (~0% change).

These negative changes impact Puerto Rico's municipalities in different magnitudes (Figure 10).

Figure 10. Percent change in social value of carbon storage capacity ($US/ ha) by municipality.



All of the municipalities experience a negative percent change in the value of carbon storage capacity as the island changes land use policy. Also, the effects of the policy change are disparate; some municipalities experience a -10% change, while the potential value of carbon storage changes by -57% in other municipalities. Areas near San Juan are the areas which experience some of the largest losses.

These values are simply potential values, but lost potential for carbon storage capacity and commensurate rents for ecosystem service provision will become increasingly important to municipalities as global carbon markets become more developed.

VII. Discussion

A. Spatial data modeling limitations

Precision and accuracy are two limitations of spatial modeling that must be considered regardless of a model's application. Accuracy is the degree to which datasets and model outputs reflect true or accepted characteristics of the land at that spatial point. Accuracy issues arise from inputs of poor quality, how well data are described and interpreted, and how many errors are contained within each dataset. There are trade-offs between cost-efficiency and higher accuracy- which can be costly and time-intensive. The level of accuracy for a model should be greater than the level at which it is being applied. For example, if a manager applies model outputs (such as ecosystem service values) at the community-level, data should be accurate to the community level or greater.

Accuracy issues arise in the context of this paper when land cover/ecosystems, which are mapped across the island, may not actually exist in that hectare of land. Also, an ecosystem may not be in the proper condition to store carbon if it is degraded. Fore example, the ecosystem may exist in that location but the function of the ecosystem is too degraded to function as mapped. The third accuracy issue is the mapping of the policy and baseline land uses. I mapped areas based on zoning, which may not occur at that sight, though it is zoned for an explicit type of land use.

Precision is the level of measurement recorded for datasets (such as meters or millimeters) and how exact that measurement is. Precision issues arise from course datasets, the scale of the measurements, and the density of recorded observations.

As with accuracy, there are trade- offs between high-precision and cost. High-precision recordings often require more intensive data collection and more expensive technology to record data. High accuracy and high precision are not substitutable; one can certainly have one without the other. Thus, extremely precise data can be inaccurate if incorrectly recorded or transferred into a digitized dataset

In the context of this paper, precision issues were more rampant for the mapping units. Baseline land use is only available in 300 ha grids, while land cover and policy land use were available in 100 ha grids. Thus, the overlay creates poor precision. Also, it may not be correct to use such an arbitrary unit of one hectare as the minimum mapping unit, given the heterogeneity of ecosystems. An example may be one hectare with multiple ecosystems, but the user must decide on one ecosystem to represent that hectare.

B. What are the limitations of mapping ES? To what extent can we model services?

Aside from accuracy and precision issues, the task of spatially modeling ecosystem services has inherent complications. Ecosystem services are a function of space and time. Space often refers to ecosystem connectivity, resource distribution, and environmental quality. Time is in reference to nutrient loading, bioaccumulation, chemical reaction time, pollutant decay, and other temporal conditions (e.g. seasons, diurnal changes).

The lack of spatially explicit models for services such as recreation and water quantity made it difficult to model these services. There was information for recreation, but few ways to describe how recreation was a function of ecosystems. Also, water quantity models existed, but model inputs for Puerto Rico data were of extremely poor quality or nonexistent. As a result of poor models and data quality, carbon storage was the only ecosystem service I was able to model with any degree of confidence.

I made the assumption that carbon will be stored 100% in 100% of the areas able to store carbon. This is simply not the case in reality. Ecosystem integrity and private landowner choice play large roles in the extent to which carbon is stored in unmanaged areas. Thus, I was limited to mapping carbon storage capacity and not actual carbon stored.

In addition, I was limited by the temporal element of modeling ecosystem services. I was limited to modeling two snapshots of carbon storage capacity because I was unable to model the rates at which ecosystems and ecosystem capacity to store carbon were likely to change over time. These ecosystem changes could include harvests, land use conversions, or ecosystem degradation. Nonetheless, I had to assume an instantaneous change from baseline to policy conditions. In doing to this, I ignored all flows and annuities of ecosystem services and instead opted to focus on the change in capacity of ecosystem services.

Another major limitation of mapping ecosystem services was the availability of precise datasets relevant to study. The carbon values were only available for certain types of ecosystems. Though the Matthews et al. 2000 study was detailed enough to describe three latitudes and more than one type of forest ecosystem, as mentioned, there is serious potential for logical accuracy problems when reclassifying Puerto Rico Helmer land cover into the same categories as the Matthews et al. 2000 study. This can inevitably affect the interpretation of the results. For example, the results show that the carbon storage capacity changes with the draft land policy. One reason may be that a significant portion of grassland appears to change into agriculture under the draft policy. In reality, a potential misclassification of “grassland” and “agriculture” in the draft plan may be the heart of the issue.

The minimum mapping units of 1ha also limited the scale of my analysis. For example, if only a portion of a 1ha cell was listed as forest, then the entire 1 ha cell was modeled as a forest ecosystem storing carbon, potentially inflating the area mapped as being able to sequester carbon.

C. What are the limitations of spatially explicit value transfers?

There few global, or even local, markets for many ecosystem services. It is often difficult to assign values to indirect or non-market benefits society receives from ecosystem services. In addition, these values change from one locale to the next, due to societal uses, resource quality, and scarcity.

Ecosystem service provision of carbon sequestration, provides global benefits, but at local costs of land preservation or opportunity costs of timber harvests. The damages of carbon emissions are of a global nature, but in varying degrees (no pun intended). Fankhauser's estimate of $20 for one metric ton of carbon is simply an average of the social damages caused by one ton of carbon. This number does not reflect the true damages incurred by asthmatics or people living on small islands vulnerable to climate change. Though, it may overestimate the marginal damages to people living in polluted areas. In the absence of a global market for carbon, it is difficult to estimate the true amount society is willing to pay to avoid damages from one ton of carbon in the atmosphere because the benefits of avoiding such damages are not uniform around the world. These realities make it difficult to transfer the marginal social value of carbon storage from one study site to another.

These problems are not specific to carbon storage. Markets for biodiversity or water quantity are so complicated that it is difficult to even isolate the social benefits derived from these services, much less place a value on them. On the contrary, markets for carbon storage are some of the better developed markets for ecosystem services.

D. How useful is a quantitative output? How does this affect policy?

There are many ecosystem services for which value has no meaning. Given the incalculable value of maintaining a climate stable enough to support life, the idea of estimating the value of carbon storage may seem obtuse. Conversely, the same argument can be made for placing a numeric monetary value on a service which has no market. In these instances, monetary values can simply be used as a policy metric for change, where the goal is not maximizing the value of a service but minimizing the negative change in services. Thus, accuracy and precision become less of an issue as the import is shifted toward modeling consistency and model parameter selection.

VIII. Conclusion

This paper shows that, even in the absence of an ideal market value for ecosystem services, effects of land use policy decisions on ecosystem services can still be modeled. The results of such models, such as negative changes in an environment's capacity to provide ecosystem services, are important inputs into the decision making process about which land use policies to adopt. Also, national policy will inevitably create disparate losses or gains throughout a policy site, but the impacts of such policies must be fully understood. This understanding includes how ecosystem services benefits - to a community or the planet - will change after a policy is implemented.

The current baseline conditions are not static; they will change over time. The draft land use plan is not the only potential land use policy, nor is it unalterable. Puerto Rico is currently receiving public comments and recommendations from the Conservation Trust of Puerto Rico. The results from this paper will provide insight into the less obvious impacts of land use policy on social benefits, both environmental and economic, provided from natural ecosystems.

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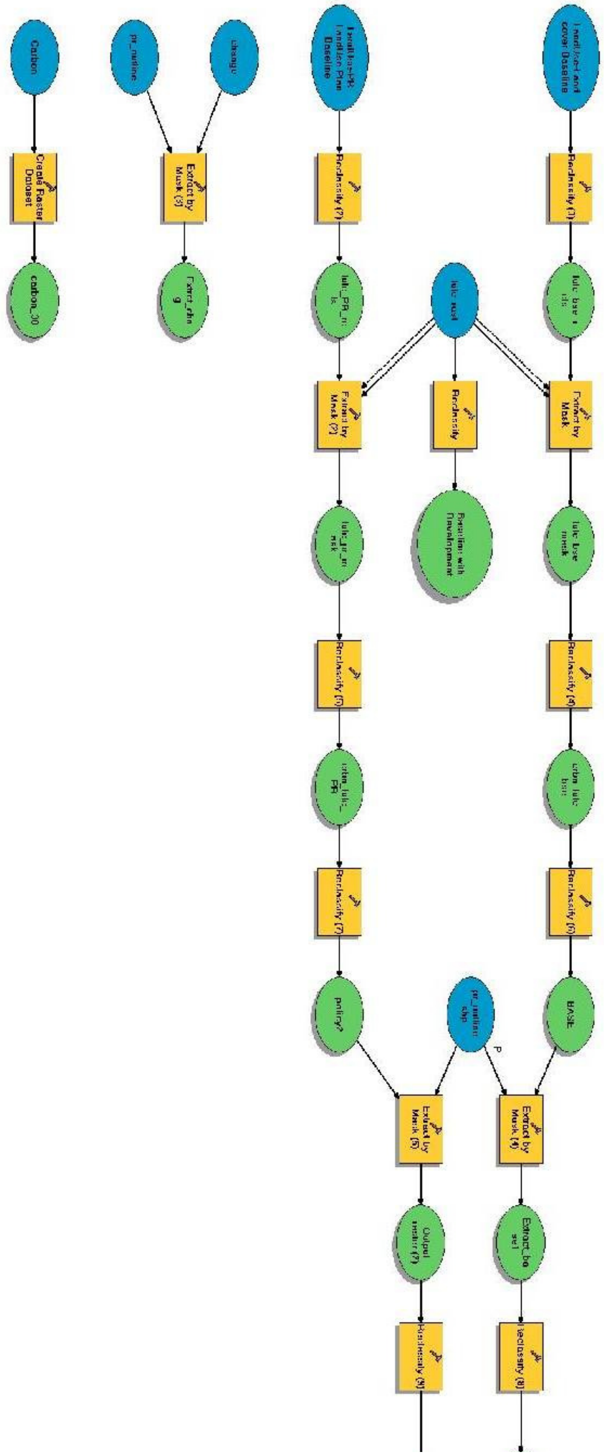
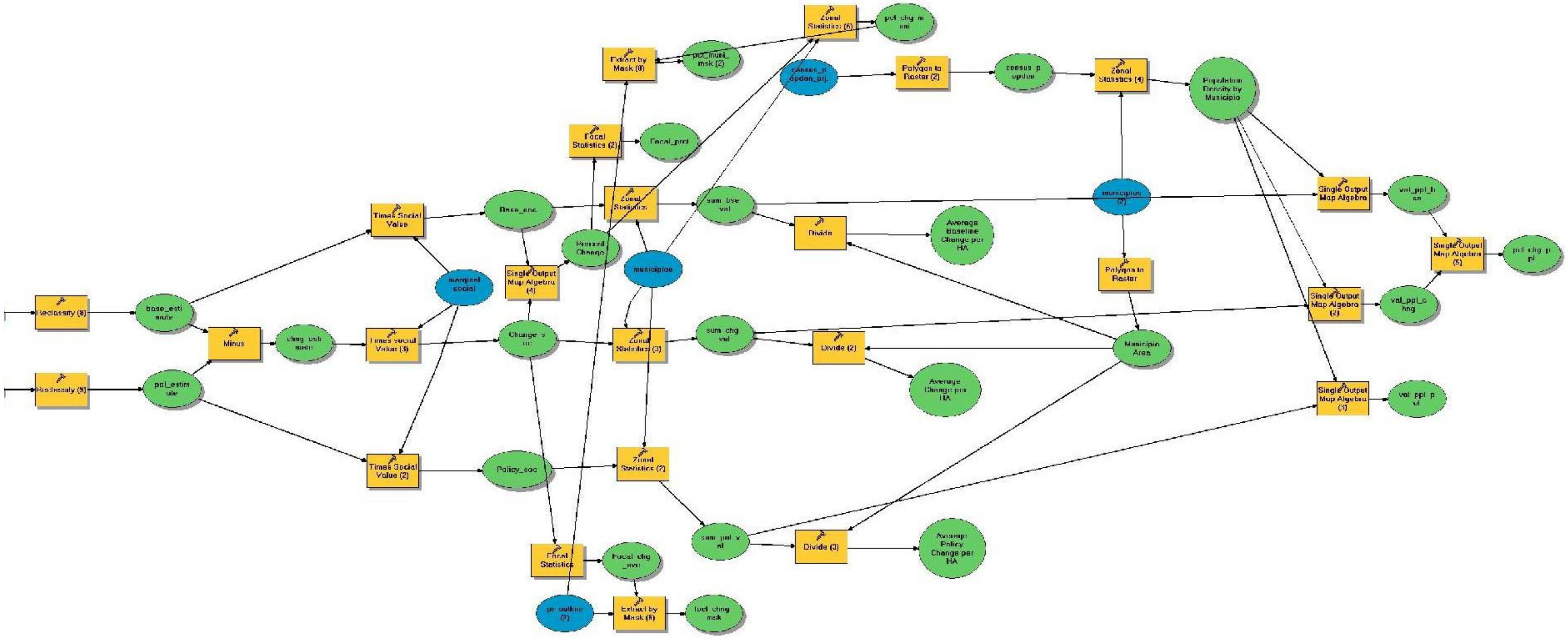
Appendix

A. Carbon Model




Reclassify (8)
Reclassify (9)
base_estimate
pol_estimate
Minus
chng_estimate
Times Social Value
Times Social Value (3)
Times Social Value (2)
marginal social
Base_soc
Change_soc
Policy_soc
Single Output Map Algebra (4)
Percent Change
Focal Statistics (2)
Focal_prct
Extract by Mask (0)
pol_muni_msk (2)
Zonal Statistics
Zonal Statistics (3)
Zonal Statistics (2)
municipios
Focal Statistics
Focal_chg_avr
pr_outline (2)
Extract by Mask (5)
foct_chng msk
sum_bse val
sum_chg val
sum_pol_v al
Divide
Divide (2)
Divide (3)
Average Baseline Change per HA
Average Change per HA
Average Policy Change per HA
Zonal Statistics (6)
pct_chg_m uni
census_p opden_prj
Polygon to Raster (2)
census_popden
Zonal Statistics (4)
Population Density by Municipio
municipios (2)
Polygon to Raster
Municipio Area
Single Output Map Algebra
Single Output Map Algebra (2)
Single Output Map Algebra (3)
Single Output Map Algebra (5)
val_ppl_b se
val_ppl_c hng
val_ppl_p ol
pct_chg_p pl

B. Carbon Model Script

```
# ---------------------------------------------------------------------------
# carbon.py
# Created on: Mon Apr 23 2007 04:16:01 PM
#   (generated by ArcGIS/ModelBuilder)
# Usage: carbon <pr_outline_shp>
# ---------------------------------------------------------------------------

# Import system modules
import sys, string, os, arcgisscripting

# Create the Geoprocessor object
gp = arcgisscripting.create()

# Check out any necessary licenses
gp.CheckOutExtension("3D")
gp.CheckOutExtension("spatial")

# Load required toolboxes...
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Spatial Analyst 
Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Conversion 
Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/3D Analyst 
Tools.tbx")

# Set the Geoprocessing environment...
gp.newPrecision = "SINGLE"
gp.XYResolution = ""
gp.XYDomain = ""
gp.scratchWorkspace = ""
gp.MTolerance = ""
gp.compression = "LZ77"
gp.coincidentPoints = "MEAN"
gp.randomGenerator = "0 ACM599"
gp.outputCoordinateSystem = ""
gp.rasterStatistics = "STATISTICS 1 1"
gp.ZDomain = ""
gp.projectCompare = "NONE"
gp.cartographicCoordinateSystem = ""
gp.configKeyword = ""
gp.outputZFlag = "Same As Input"
gp.qualifiedFieldNames = "true"
gp.tileSize = "128 128"
gp.pyramid = "PYRAMIDS -1 NEAREST"
gp.referenceScale = ""
gp.extent = "DEFAULT"
gp.XYTolerance = ""
gp.MDomain = ""
gp.spatialGrid1 = "0"
gp.cellSize = "MAXOF"
gp.outputZValue = ""
gp.outputMFlag = "Same As Input"
gp.geographicTransformations = ""
gp.spatialGrid2 = "0"
gp.ZResolution = ""
gp.mask = ""
```

```
gp.spatialGrid3 = "0"
gp.workspace = ""
gp.MResolution = ""
gp.derivedPrecision = "HIGHEST"
gp.ZTolerance = ""

# Script arguments...
pr_outline_shp = sys.argv[1]
if pr_outline_shp == '#':
 pr_outline_shp =
"z:\\extrastorage\\PR_Exp\\Puerto_Rico_Exp\\Base\\pr_outline.shp" # provide a
default value if unspecified

# Local variables...
Baseline_with_Development = "z:\\MP\\PR data\\Carbon\\lulc_reclass"
lulc_rast = "z:\\MP\\PR data\\Carbon\\lulc_rast"
LandUse-PR_LandUse_Plan_Baseline = "LandUse-PR LandUse Plan Baseline"
lulc_PR_rcls = "z:\\MP\\PR data\\Carbon\\lulc_PR_rcls"
lulc_bse_rcls = "z:\\MP\\PR data\\Carbon\\lulc_bse_rcls"
LandUse-Landcover_Baseline = "LandUse-Landcover Baseline"
lulc_bse_mask = "z:\\MP\\PR data\\Carbon\\lulc_bse_mask"
lulc_pr_mask = "z:\\MP\\PR data\\Carbon\\lulc_pr_mask"
crbn_lulc_bse = "z:\\MP\\PR data\\Carbon\\crbn_lulc_bse"
crbn_lulc_PR = "z:\\MP\\PR data\\Carbon\\crbn_lulc_PR"
BASE = "z:\\MP\\PR data\\Carbon\\base"
policy2 = "z:\\MP\\PR data\\Carbon\\policy2"
Extract_base1 = "z:\\MP\\PR data\\Carbon\\Extract_base1"
Output_raster__2_ = "z:\\MP\\PR data\\Carbon\\Extract_poli1"
base_estimate = "z:\\MP\\PR data\\Carbon\\base_estimate"
pol_estimate = "z:\\MP\\PR data\\Carbon\\pol_estimate"
chng_estimate = "z:\\MP\\PR data\\Carbon\\chng_estimate"
Base_soc = "z:\\MP\\PR data\\Carbon\\base_soc_val"
marginal_social_value = "20"
Policy_soc = "z:\\MP\\PR data\\Carbon\\pol_soc_val"
sum_bse_val = "z:\\MP\\PR data\\Carbon\\sum_bse_val"
Change_soc = "z:\\MP\\PR data\\Carbon\\chng_soc_val"
municipios = "municipios"
sum_pol_val = "z:\\MP\\PR data\\Carbon\\sum_pol_val"
sum_chg_val = "z:\\MP\\PR data\\Carbon\\sum_chg_val"
Municipio_Area = "z:\\MP\\PR data\\Carbon\\muni_raster"
municipios__2_ = "municipios"
Average_Baseline_Change_per_HA = "z:\\MP\\PR data\\Carbon\\wght_bse_val"
Average_Change_per_HA = "z:\\MP\\PR data\\Carbon\\wght_chg_val"
Average_Policy_Change_per_HA = "z:\\MP\\PR data\\Carbon\\wght_pol_val"
census_popden_prj_shp = "z:\\MP\\PR data\\WORKSPACE\\census_popden_prj.shp"
Population_Density_by_Municipio = "z:\\MP\\PR data\\Carbon\\popden_muni"
census_popden = "z:\\MP\\PR data\\Carbon\\census_popden"
val_ppl_bse = "z:\\MP\\PR data\\Carbon\\val_ppl_bse"
val_ppl_chng = "z:\\MP\\PR data\\Carbon\\val_ppl_chng"
val_ppl_pol = "z:\\MP\\PR data\\Carbon\\val_ppl_pol"
Focal_chg_ave = "z:\\MP\\PR data\\Carbon\\Focal_chg_ave"
focl_chng_msk = "z:\\MP\\PR data\\Carbon\\focl_chng_msk"
pr_outline__2_ = "pr_outline"
Percent_Change = "z:\\MP\\PR data\\Carbon\\prct_chg"
Focal_prct = "z:\\MP\\PR data\\Carbon\\Focal_prct"
pct_muni_msk__2_ = "z:\\MP\\PR data\\Carbon\\pct_muni_msk"
pct_chg_muni = "z:\\MP\\PR data\\Carbon\\pct_chg_muni"
```

```
pct_chg_ppl = "z:\\MP\\PR data\\Carbon\\pct_chg_ppl"

# Process: Reclassify...
gp.Reclassify_3d(lulc_rast, "VALUE", "0 0;1 0;2 0;3 3;4 1;5 3;6 4;7 4;8 4;9
4;10 3;11 4;12 2;13 2;14 4;15 1;16 3;17 4;18 4;19 3;20 4;21 4;22 1;23 4;24
4;25 1;26 0;27 4;28 4;29 1;30 1;31 0", Baseline_with_Development, "NODATA")

# Process: Reclassify (3)...
gp.Reclassify_sa(LandUse-Landcover_Baseline, "VALUE", "6 1;9 1;10 1;13 1;14
1;16 NODATA;22 NODATA;23 NODATA;25 NODATA;26 NODATA;28 NODATA",
lulc_bse_rcls, "DATA")

# Process: Extract by Mask...
tempEnvironment0 = gp.newPrecision
gp.newPrecision = "SINGLE"
tempEnvironment1 = gp.XYResolution
gp.XYResolution = ""
tempEnvironment2 = gp.XYDomain
gp.XYDomain = ""
tempEnvironment3 = gp.scratchWorkspace
gp.scratchWorkspace = ""
tempEnvironment4 = gp.MTolerance
gp.MTolerance = ""
tempEnvironment5 = gp.compression
gp.compression = "LZ77"
tempEnvironment6 = gp.coincidentPoints
gp.coincidentPoints = "MEAN"
tempEnvironment7 = gp.randomGenerator
gp.randomGenerator = "0 ACM599"
tempEnvironment8 = gp.outputCoordinateSystem
gp.outputCoordinateSystem = ""
tempEnvironment9 = gp.rasterStatistics
gp.rasterStatistics = "STATISTICS 1 1"
tempEnvironment10 = gp.ZDomain
gp.ZDomain = ""
tempEnvironment11 = gp.projectCompare
gp.projectCompare = "NONE"
tempEnvironment12 = gp.cartographicCoordinateSystem
gp.cartographicCoordinateSystem = ""
tempEnvironment13 = gp.configKeyword
gp.configKeyword = ""
tempEnvironment14 = gp.outputZFlag
gp.outputZFlag = "Same As Input"
tempEnvironment15 = gp.qualifiedFieldNames
gp.qualifiedFieldNames = "true"
tempEnvironment16 = gp.tileSize
gp.tileSize = "128 128"
tempEnvironment17 = gp.pyramid
gp.pyramid = "PYRAMIDS -1 NEAREST"
tempEnvironment18 = gp.referenceScale
gp.referenceScale = ""
tempEnvironment19 = gp.extent
gp.extent = "DEFAULT"
tempEnvironment20 = gp.XYTolerance
gp.XYTolerance = ""
tempEnvironment21 = gp.MDomain
gp.MDomain = ""
```

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tempEnvironment22 = gp.spatialGrid1
gp.spatialGrid1 = "0"
tempEnvironment23 = gp.outputZValue
gp.outputZValue = ""
tempEnvironment24 = gp.outputMFlag
gp.outputMFlag = "Same As Input"
tempEnvironment25 = gp.geographicTransformations
gp.geographicTransformations = ""
tempEnvironment26 = gp.spatialGrid2
gp.spatialGrid2 = "0"
tempEnvironment27 = gp.ZResolution
gp.ZResolution = ""
tempEnvironment28 = gp.mask
gp.mask = ""
tempEnvironment29 = gp.spatialGrid3
gp.spatialGrid3 = "0"
tempEnvironment30 = gp.workspace
gp.workspace = ""
tempEnvironment31 = gp.MResolution
gp.MResolution = ""
tempEnvironment32 = gp.derivedPrecision
gp.derivedPrecision = "HIGHEST"
tempEnvironment33 = gp.ZTolerance
gp.ZTolerance = ""
gp.ExtractByMask_sa(lulc_rast, lulc_bse_rcls, lulc_bse_mask)
gp.newPrecision = tempEnvironment0
gp.XYResolution = tempEnvironment1
gp.XYDomain = tempEnvironment2
gp.scratchWorkspace = tempEnvironment3
gp.MTolerance = tempEnvironment4
gp.compression = tempEnvironment5
gp.coincidentPoints = tempEnvironment6
gp.randomGenerator = tempEnvironment7
gp.outputCoordinateSystem = tempEnvironment8
gp.rasterStatistics = tempEnvironment9
gp.ZDomain = tempEnvironment10
gp.projectCompare = tempEnvironment11
gp.cartographicCoordinateSystem = tempEnvironment12
gp.configKeyword = tempEnvironment13
gp.outputZFlag = tempEnvironment14
gp.qualifiedFieldNames = tempEnvironment15
gp.tileSize = tempEnvironment16
gp.pyramid = tempEnvironment17
gp.referenceScale = tempEnvironment18
gp.extent = tempEnvironment19
gp.XYTolerance = tempEnvironment20
gp.MDomain = tempEnvironment21
gp.spatialGrid1 = tempEnvironment22
gp.outputZValue = tempEnvironment23
gp.outputMFlag = tempEnvironment24
gp.geographicTransformations = tempEnvironment25
gp.spatialGrid2 = tempEnvironment26
gp.ZResolution = tempEnvironment27
gp.mask = tempEnvironment28
gp.spatialGrid3 = tempEnvironment29
gp.workspace = tempEnvironment30
gp.MResolution = tempEnvironment31
```

```
gp.derivedPrecision = tempEnvironment32
gp.ZTolerance = tempEnvironment33

# Process: Reclassify (4)...
gp.Reclassify_sa(lulc_bse_mask, "VALUE", "0 0;1 0;2 0;3 3;4 1;5 3;6 4;7 4;8
4;9 4;10 3;11 4;12 2;13 2;14 4;15 1;16 3;17 4;18 4;19 3;20 4;21 4;22 1;23
4;24 4;25 1;26 0;27 4;28 4;29 1;30 1;31 0", crbn_lulc_bse, "DATA")

# Process: Reclassify (6)...
gp.Reclassify_3d(crbn_lulc_bse, "VALUE", "0 0;1 1;2 2;3 3;4 4;NODATA 0",
BASE, "DATA")

# Process: Extract by Mask (4)...
gp.ExtractByMask_sa(BASE, pr_outline_shp, Extract_base1)

# Process: Reclassify (8)...
gp.Reclassify_sa(Extract_base1, "VALUE", "0 0;1 43;2 91;3 110;4 140",
base_estimate, "DATA")

# Process: Times Social Value...
gp.Times_sa(base_estimate, marginal_social_value, Base_soc)

# Process: Zonal Statistics...
gp.ZonalStatistics_sa(municipios, "MUNICIPIO", Base_soc, sum_bse_val, "SUM",
"DATA")

# Process: Polygon to Raster...
gp.PolygonToRaster_conversion(municipios__2_, "areas_ha", Municipio_Area,
"CELL_CENTER", "NONE", "100")

# Process: Divide...
gp.Divide_sa(sum_bse_val, Municipio_Area, Average_Baseline_Change_per_HA)

# Process: Reclassify (2)...
gp.Reclassify_sa(LandUse-PR_LandUse_Plan_Baseline, "VALUE", "6 1;9 1;10 1;13
1;14 1;16 1;22 NODATA;23 NODATA;25 NODATA;26 NODATA;28 NODATA", lulc_PR_rcls,
"DATA")

# Process: Extract by Mask (2)...
tempEnvironment0 = gp.newPrecision
gp.newPrecision = "SINGLE"
tempEnvironment1 = gp.XYResolution
gp.XYResolution = ""
tempEnvironment2 = gp.XYDomain
gp.XYDomain = ""
tempEnvironment3 = gp.scratchWorkspace
gp.scratchWorkspace = "z:\\MP\\PR data\\Carbon"
tempEnvironment4 = gp.MTolerance
gp.MTolerance = ""
tempEnvironment5 = gp.compression
gp.compression = "LZ77"
tempEnvironment6 = gp.coincidentPoints
gp.coincidentPoints = "MEAN"
tempEnvironment7 = gp.randomGenerator
gp.randomGenerator = "0 ACM599"
tempEnvironment8 = gp.outputCoordinateSystem
gp.outputCoordinateSystem = ""
```

```
tempEnvironment9 = gp.rasterStatistics
gp.rasterStatistics = "STATISTICS 1 1"
tempEnvironment10 = gp.ZDomain
gp.ZDomain = ""
tempEnvironment11 = gp.projectCompare
gp.projectCompare = "NONE"
tempEnvironment12 = gp.cartographicCoordinateSystem
gp.cartographicCoordinateSystem = ""
tempEnvironment13 = gp.configKeyword
gp.configKeyword = ""
tempEnvironment14 = gp.outputZFlag
gp.outputZFlag = "Same As Input"
tempEnvironment15 = gp.qualifiedFieldNames
gp.qualifiedFieldNames = "true"
tempEnvironment16 = gp.tileSize
gp.tileSize = "128 128"
tempEnvironment17 = gp.pyramid
gp.pyramid = "PYRAMIDS -1 NEAREST"
tempEnvironment18 = gp.referenceScale
gp.referenceScale = ""
tempEnvironment19 = gp.extent
gp.extent = "DEFAULT"
tempEnvironment20 = gp.XYTolerance
gp.XYTolerance = ""
tempEnvironment21 = gp.MDomain
gp.MDomain = ""
tempEnvironment22 = gp.spatialGrid1
gp.spatialGrid1 = "0"
tempEnvironment23 = gp.outputZValue
gp.outputZValue = ""
tempEnvironment24 = gp.outputMFlag
gp.outputMFlag = "Same As Input"
tempEnvironment25 = gp.geographicTransformations
gp.geographicTransformations = ""
tempEnvironment26 = gp.spatialGrid2
gp.spatialGrid2 = "0"
tempEnvironment27 = gp.ZResolution
gp.ZResolution = ""
tempEnvironment28 = gp.mask
gp.mask = ""
tempEnvironment29 = gp.spatialGrid3
gp.spatialGrid3 = "0"
tempEnvironment30 = gp.workspace
gp.workspace = "z:\\MP\\PR data\\Carbon"
tempEnvironment31 = gp.MResolution
gp.MResolution = ""
tempEnvironment32 = gp.derivedPrecision
gp.derivedPrecision = "HIGHEST"
tempEnvironment33 = gp.ZTolerance
gp.ZTolerance = ""
gp.ExtractByMask_sa(lulc_rast, lulc_PR_rcls, lulc_pr_mask)
gp.newPrecision = tempEnvironment0
gp.XYResolution = tempEnvironment1
gp.XYDomain = tempEnvironment2
gp.scratchWorkspace = tempEnvironment3
gp.MTolerance = tempEnvironment4
gp.compression = tempEnvironment5
```

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gp.coincidentPoints = tempEnvironment6
gp.randomGenerator = tempEnvironment7
gp.outputCoordinateSystem = tempEnvironment8
gp.rasterStatistics = tempEnvironment9
gp.ZDomain = tempEnvironment10
gp.projectCompare = tempEnvironment11
gp.cartographicCoordinateSystem = tempEnvironment12
gp.configKeyword = tempEnvironment13
gp.outputZFlag = tempEnvironment14
gp.qualifiedFieldNames = tempEnvironment15
gp.tileSize = tempEnvironment16
gp.pyramid = tempEnvironment17
gp.referenceScale = tempEnvironment18
gp.extent = tempEnvironment19
gp.XYTolerance = tempEnvironment20
gp.MDomain = tempEnvironment21
gp.spatialGrid1 = tempEnvironment22
gp.outputZValue = tempEnvironment23
gp.outputMFlag = tempEnvironment24
gp.geographicTransformations = tempEnvironment25
gp.spatialGrid2 = tempEnvironment26
gp.ZResolution = tempEnvironment27
gp.mask = tempEnvironment28
gp.spatialGrid3 = tempEnvironment29
gp.workspace = tempEnvironment30
gp.MResolution = tempEnvironment31
gp.derivedPrecision = tempEnvironment32
gp.ZTolerance = tempEnvironment33

# Process: Reclassify (5)...
gp.Reclassify_sa(lulc_pr_mask, "VALUE", "0 0;1 0;2 0;3 3;4 1;5 3;6 4;7 4;8
4;9 4;10 3;11 4;12 2;13 2;14 4;15 1;16 3;17 4;18 4;19 3;20 4;21 4;22 1;23
4;24 4;25 1;26 0;27 4;28 4;29 1;30 1;31 0", crbn_lulc_PR, "DATA")

# Process: Reclassify (7)...
gp.Reclassify_sa(crbn_lulc_PR, "VALUE", "0 0;1 1;2 2;3 3;4 4;NODATA 0",
policy2, "DATA")

# Process: Extract by Mask (5)...
gp.ExtractByMask_sa(policy2, pr_outline_shp, Output_raster__2_)

# Process: Reclassify (9)...
gp.Reclassify_sa(Output_raster__2_, "VALUE", "0 0;1 43;2 91;3 110;4 140",
pol_estimate, "DATA")

# Process: Minus...
gp.Minus_sa(pol_estimate, base_estimate, chng_estimate)

# Process: Times social Value (3)...
gp.Times_sa(chng_estimate, marginal_social_value, Change_soc)

# Process: Zonal Statistics (3)...
gp.ZonalStatistics_sa(municipios, "MUNICIPIO", Change_soc, sum_chg_val,
"SUM", "DATA")

# Process: Divide (2)...
gp.Divide_sa(sum_chg_val, Municipio_Area, Average_Change_per_HA)
```

```
# Process: Times Social Value (2)...
gp.Times_sa(pol_estimate, marginal_social_value, Policy_soc)

# Process: Zonal Statistics (2)...
gp.ZonalStatistics_sa(municipios, "MUNICIPIO", Policy_soc, sum_pol_val,
"SUM", "DATA")

# Process: Divide (3)...
gp.Divide_sa(sum_pol_val, Municipio_Area, Average_Policy_Change_per_HA)

# Process: Polygon to Raster (2)...
gp.PolygonToRaster_conversion(census_popden_prj_shp, "pop_den_HA",
census_popden, "CELL_CENTER", "NONE", "100")

# Process: Zonal Statistics (4)...
gp.ZonalStatistics_sa(municipios__2_, "MUNICIPIO", census_popden,
Population_Density_by_Municipio, "SUM", "DATA")

# Process: Single Output Map Algebra (3)...
gp.SingleOutputMapAlgebra_sa("[sum_pol_val]/ [Population Density by
Municipio]", val_ppl_pol, "'z:\\MP\\PR data\\Carbon\\popden_muni';'z:\\MP\\PR
data\\Carbon\\sum_pol_val'")

# Process: Focal Statistics...
gp.FocalStatistics_sa(Change_soc, Focal_chg_ave, "Rectangle 10 10 CELL",
"MEAN", "DATA")

# Process: Extract by Mask (6)...
gp.ExtractByMask_sa(Focal_chg_ave, pr_outline__2_, focl_chng_msk)

# Process: Single Output Map Algebra (4)...
gp.SingleOutputMapAlgebra_sa("100.00*([Change_soc]/ [Base_soc])",
Percent_Change, "'z:\\MP\\PR data\\Carbon\\chng_soc_val';'z:\\MP\\PR
data\\Carbon\\base_soc_val'")

# Process: Focal Statistics (2)...
gp.FocalStatistics_sa(Percent_Change, Focal_prct, "Rectangle 10 10 CELL",
"MEAN", "DATA")

# Process: Zonal Statistics (6)...
gp.ZonalStatistics_sa(municipios, "MUNICIPIO", Percent_Change, pct_chg_muni,
"MEAN", "DATA")

# Process: Extract by Mask (8)...
gp.ExtractByMask_sa(pct_chg_muni, pr_outline__2_, pct_muni_msk__2_)

# Process: Single Output Map Algebra...
gp.SingleOutputMapAlgebra_sa("[sum_bse_val]/ [Population Density by
Municipio]", val_ppl_bse, "'z:\\MP\\PR data\\Carbon\\popden_muni';'z:\\MP\\PR
data\\Carbon\\sum_bse_val'")

# Process: Single Output Map Algebra (2)...
gp.SingleOutputMapAlgebra_sa("[sum_chg_val] / [Population Density by
Municipio]", val_ppl_chng, "'z:\\MP\\PR
data\\Carbon\\popden_muni';'z:\\MP\\PR data\\Carbon\\sum_chg_val'")
```

```
# Process: Single Output Map Algebra (5)...
gp.SingleOutputMapAlgebra_sa("[val_ppl_chng]/ [val_ppl_bse]", pct_chg_ppl,
"'z:\\MP\\PR data\\Carbon\\val_ppl_bse';'z:\\MP\\PR
data\\Carbon\\val_ppl_chng'")
```

C. Security Agreement

(between Miranda Smith and Nature Serve and the government of Puerto Rico)

1. The data is provided for research purposes only for use solely by Miranda Smith

2. The data will be stored in a secure location accessible only Miranda Smith and lab or data managers/technicians

3. All those with access to the data will be informed of these security requirements

4. The original data will be destroyed after their use; Miranda Smith may retain products of the use of the data (secondary maps/tabular results) that do not reveal specific land uses.

5. Miranda Smith may demonstrate the data and secondary results but may not publish digital or printed maps of the original land use plan without written permission by NatureServe.