Land-Cover / Land-Use Change Program

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Progress Report

Project Title: Vulnerability and adaptive management of tropical coastal wetlands in the context of land use and climate changes

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Abstract:

The tropical island of Puerto Rico leads the reforestation in the Central and South American which supports the Forest Transition Model with the economic shift from agriculture to industry and service as the main driver. Urbanization and urban sprawl happened during the process of reforestation due to the migration of rural people to urban after agriculture abandonment. While the reforestation may connect and aggregate forest patches, urbanization and urban sprawl may reverse the trend. The key objective of the project is to answer the scientific question of "How the land cover and land use changes, interacting with the climate change, impact the vulnerability of tropical coastal wetlands spatiotemporally?"

During the report period, we complete the analysis of the land cover / land use changes and consequent landscape fragmentation at both large and small scales, and investigate the mechanisms of the land fragmentation dynamics by quantifying the relationship between spatiotemporal pattern of fragmentation and the biophysical and socioeconomic factors. We also investigate the impacts of sea level rise on coastal wetlands by simulating the changes in wetlands distribution using the Sea Level Affecting Marshes Model (SLAMM) under different sea level rise scenarios. We started the studies of the impacts of regulations and policies on wetlands changes and the simulation of the dynamics of watersheds that feed the wetlands, which are expected to complete in 2014.

Our results indicate that: Despite of the overall trend of reforestation, forests are getting fragmented in Puerto Rico primarily due to urban sprawl and deforestation in forest interiors. However, vegetated wetlands are aggregated because of the implementation of laws and regulations on wetlands protection. The accelerated urban sprawl, indicated by the faster shift of peak fragmentation towards rural areas, 0.10 and 0.19 km yr^{-1} for the periods of 1977-1991 and

1991-2000, respectively, was accompanied by the large urban patches formed in near suburban, and synchronized with the shift of peak forest fragmentation, indicating progressively more forest fragmentation in forest interiors.

There are significant changes from marsh and swamp to mangrove, and inland freshwater marsh / undeveloped upland to regularly flooded marsh and mangroves under the scenario of 1.5 m sea level rise. The changes from the freshwater marsh to the saltwater mangroves and the migration limitation of wetlands surrounded by urban development imply future shrinking of coastal wetlands with sea level rise, especially the freshwater wetlands, and great impacts on wetlands hydrology, structures, functions, and biodiversity.

Progress:

1) *Land Cover / Land Use Changes and Consequent Dynamics of Land Fragmentation from 1977 to 2000*

We analyzed the land cover maps of 1977, 1991, and 2000 developed by the USDA Forest Service (Helmer et al. 2002, Kennaway and Helmer 2007), the Puerto Rico Department of the Natural and Environmental Resources, and the US Geological Survey Caribbean Division. The land cover maps for 1991 and 2000 were derived from the Landsat TM/ETM images using decision tree classification and the map for 1977 was visually interpreted from the aerial photos. Therefore, the absolute values of fragmentation indices were only compared between 1991 and 2000, and the patterns of fragmentation were compared among all the three years.

To explore the mechanisms of the land fragmentation dynamics during the courses of urban sprawl and reforestation, we quantify the relationship between spatiotemporal pattern of fragmentation and the biophysical and socioeconomic factors. The biophysical and socioeconomic variables of elevation, slope, distance to urban centers, and population density were considered as the potential causal factors of fragmentation dynamics.

Table 1 Assessment of average increments of the fragmentation indices between 1991 and 2000. ‘**’ and ‘*’ indicate the levels of significance with *p* value less than 0.01 and 0.05, respectively.

Fragmentation index		Urban	Forest	Wetland
AREA_MN	Intercept	-0.2	-22.2**	3.4**
	Relative change	-0.08	-0.43	0.49
LPI	Intercept	0.73**	0.57*	0.42*
	Relative change	0.10	0.016	0.10
EDGE_AREA	Intercept	-8.5*	-10.3	-17.0
	Relative change	-0.01	-0.04	-0.03

ED	Intercept	3.8*	3.3*	-6.19**
	Relative change	0.07	0.04	-0.18

From 1991 to 2000, the significantly reduced AREA_MN (Mean Patch Area) and enhanced ED (Edge Density) are strong indicators of increased fragmentation of both urban and forest. The results suggested a general trend that a small number of large patches of urban and forest in the big cells may get more aggregated.

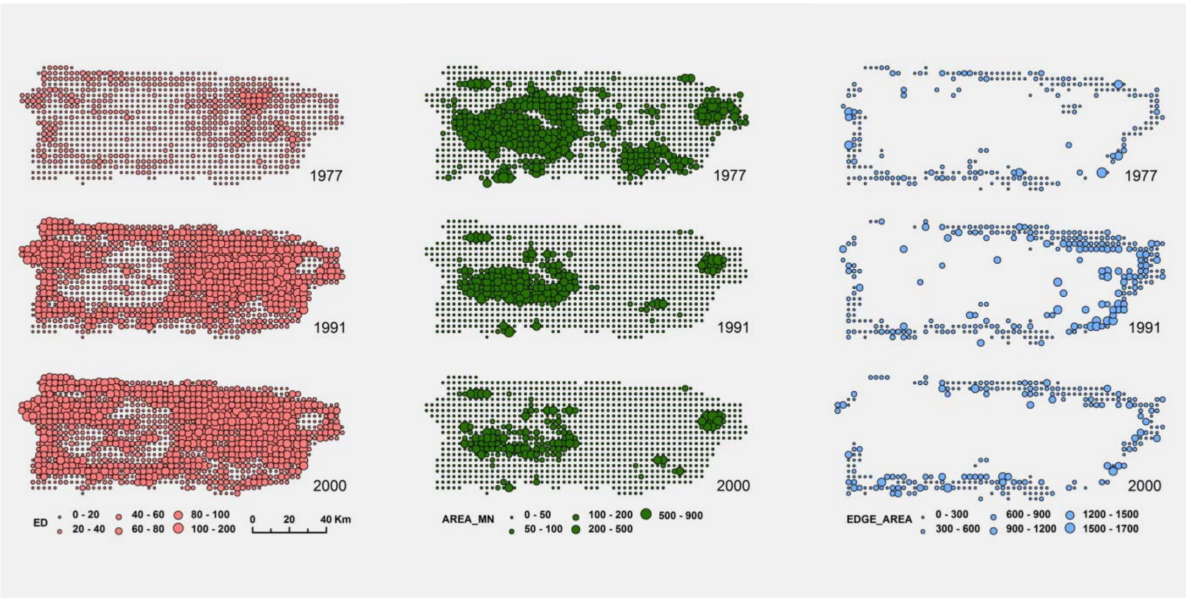

Fig. 1 Fragmentation dynamics of urban, forest, and wetland in 1977, 1991, and 2000

The fragmentation indices showed different spatial and temporal patterns for urban, forests, and wetlands (Fig. 1). The urban fragmentation is low inside the urban areas and tends to be high at the suburban areas. On the contrary, the forest fragmentation tends to be low in the rural areas, such as the central mountains. In general the fragmentation of urban and forests increased from 1991 to 2000, e.g. the increased ED and decreased AREA_MN. However, the decreased wetland fragmentation over the same period, especially in the eastern part of the island, indicates wetlands aggregation.

The urban EDGE_AREA (Edge to Area Ratio) is found to be a quadratic function of the distance to urban (*D*), and the index increased with the slope (*s*) and decreased with the heterogeneity of the slope (σ_s) and the population density. The ED of forest increases with the first order of *D* and *s*, but decreases with σ_s . The negative second order term of *D* indicates existence of a maximum edge density for both 1991 and 2000.

2) *Impacts of sea level rise on coastal wetlands*

Coastal wetlands are extremely vulnerable to sea level rise and the wetland soil formation can hardly balance the effects of predicted sea level rise (Morris et al. 2002). The migration of coastal wetlands to inland due to sea level rise can be limited by the coastal development which forms the phenomenon of "coastal squeeze". We choose an extensive freshwater marsh in Toa Baja, Puerto Rico to study the impacts of sea level rise on coastal wetlands since this marsh provides a critical habitat for an endangered species of *Eleutherodactylys juanariveroi* and represents the historical land cover/land use changes in Puerto Rico. Most of the wetlands were drained for intensive agricultural activities in 1930s (Fig. 2). The agricultural lands were then gradually abandoned and accompanied with initial urban development in 1970s. Wetlands were further restored with the disappearance of agriculture, but surrounded by urbanization which squeezed the wetlands and blocked the migration of the wetlands to inland.

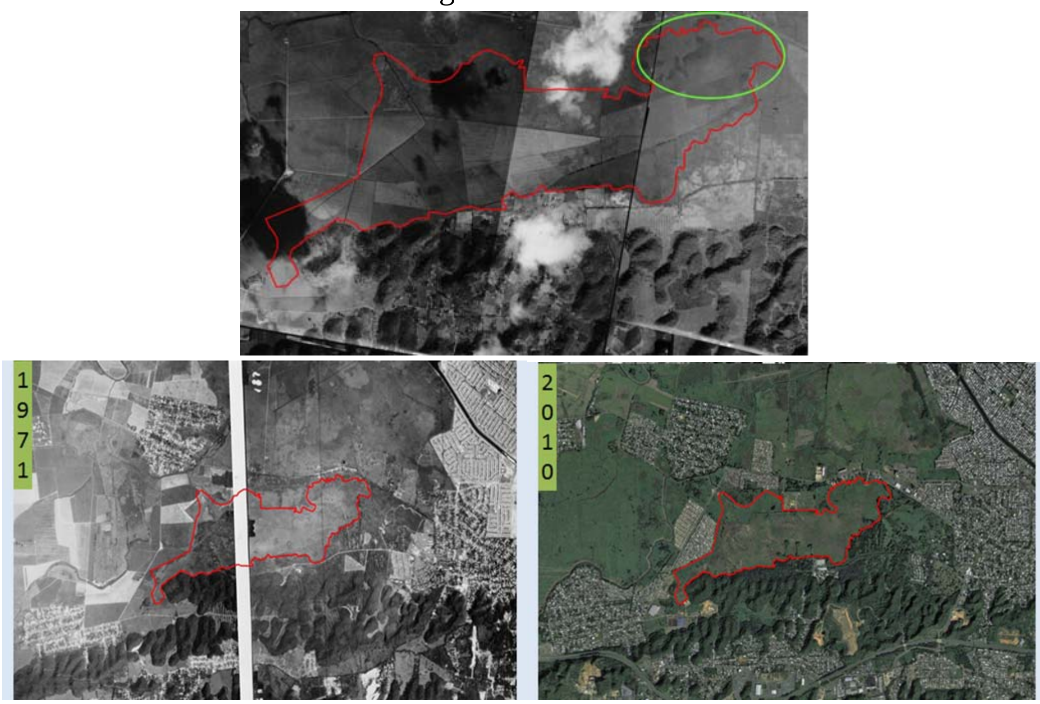

Fig. 2 Land Cover Land Use Changes in the wetlands of Toa Baja, Puerto Rico from 1930s to 1971 and 2010.

We applied the Sea Level Affecting Marshes Model (SLAMM) to simulate the impacts of predicted sea level rise by 2100 on the distribution of wetlands. The inputs of the SLAMM include three spatial datasets: DEM, slope, and current wetlands distribution. The DEM used is a Lidar-derived one at the resolution of 5 m. The slope dataset was created from the DEM using the ArcGIS. The current wetlands distribution was from the National Wetlands Inventory (NWI), and the developed area was delineated based on the visual interpretation of the aerial photos taken in 2010. The wetlands classification of NWI was reclassified into the system adopted in the SLAMM. The predicted sea level rise ranged from the 0.59 m by the 4th IPCC Report in 2007, to 5 m by 2100 in recent studies (Rahmstorf et al. 2012). We chose the scenarios of sea level rise of

1, 1.5, and 2 meters, and simulated their impacts on the wetlands distribution in Toa Baja, Puerto Rico.

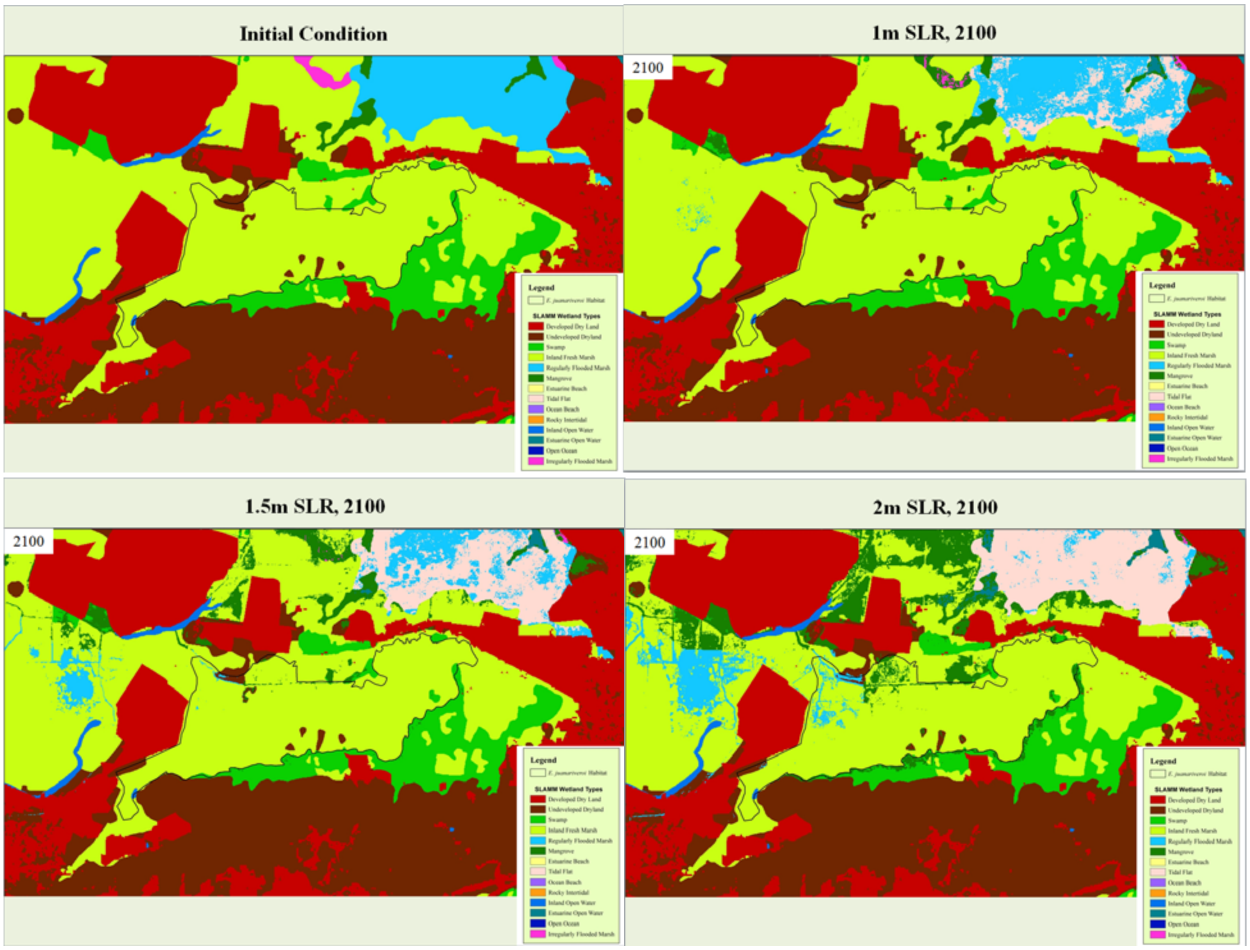

Fig. 3 Simulated coastal wetlands distribution in Toa Baja, Puerto Rico, under the scenarios of 1, 1.5, and 2 m of sea level rise by 2100, using the Sea Level Affecting Marshes Model.

There are small patches of marsh and swamp converted to mangroves, small areas of marsh changed to tidal flats, and very small areas of inland freshwater marsh to regularly flooded marsh under the scenario of 1 m sea level rise (Fig. 3). Significant changes from marsh and swamp to mangrove, and inland freshwater marsh / undeveloped upland to regularly flooded marsh and mangroves can be seen in the scenario of 1.5 m sea level rise. Mangroves are significantly expanded into previous inland freshwater marsh, and most of the regularly flooded marsh was changed into tidal flats under the scenario of 2 m sea level rise. The changes from the freshwater marsh to the saltwater mangroves and the migration limitation of wetlands surrounded by urban development imply future shrinking of coastal wetlands, especially the freshwater wetlands, and great impacts on wetlands hydrology, structures, functions, and biodiversity.

Manuscripts and Presentations/Posters:

Gao, Q. and Yu, M., *Discerning the fragmentation dynamics between tropical forest and wetlands in the context of reforestation, urban sprawl, and policy change*. Ready to submit

Villanueva, L. and Yu, M., *Distribution of vegetative wetlands in Puerto Rico and its relationship with policy change*. In preparation

Davila, D. Yu, M. and Villanueva, L., *Impacts of sea level rise on coastal wetlands in Puerto Rico*. In preparation

Yu, M. and Qiong Gao. Apr. 2, 2013. Presentation at the Annual Science Meeting of NASA Land Cover and Land Use Change Program, Washington, D.C. *Vulnerability and Adaptive Management of Tropical Coastal Wetlands in the context of Land Use and Climate Changes*

Villanueva, L. and Yu, M. Apr. 2, 2013. Poster at the Annual Science Meeting of NASA Land Cover and Land Use Change Program, Washington, D.C. *Changes in Vegetative Wetland and Coastal Forest Cover in the Northeast Ecological Corridor after Agriculture Decline in Puerto Rico*

Davila, D. Apr. 2, 2013. Poster at the Annual Science Meeting of NASA Land Cover and Land Use Change Program, Washington, D.C. *Vulnerability of the coqui llanero, Eleutherodactylus juanariveroi, habitat to sea level rise*

Villanueva, L. and Yu, M. Nov. 3, 2013. Poster at the Coastal and Estuarine Research Federation Conference, San Diego, CA. *Puerto Rico's Coastal Vegetative Wetlands in the context of Socio-Economic and Climate Changes*