Beyond *People & Pixels*: Integrating People & Environment in LULC Studies

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Abstract: The fusion of multi-resolution remotely-sensed imagery, an ecological, niche-based, habitat model, demographic descriptions of people and land from population and agricultural census data, and social surveys, longitudinal and cross-sectional, are used to understand the direct and indirect consequences of population-environment interactions on LULC change in the Ecuadorian Amazon Frontier and the Galapagos Islands of Ecuador. Both sites are unique in several ways – for the Amazon, rich biological and cultural diversity that is challenged by deforestation, agricultural extensification, and urbanization, while in the Galapagos, the consumptive demands of a burgeoning human population, composed of migrants from the Ecuadorian mainland and international tourists, are affecting native and endemic species and the integrity of terrestrial and marine protected areas. The intent is to examine approaches for defining "social spaces" to assess population-environment interactions, using methods that characterize and model the endogenous and exogenous drivers of LULC change.

Introduction & Problem

Increasingly, land use/land cover (LULC) studies are extending the representation of the human dimension and their associated "social spaces" to include not only the land that people directly use or own, but also to land that is "influenced" by individuals, households, extended households, and broader social units through the power and influence they exert and the decision-making that is made at local, regional, and global levels. In our studies in the Ecuadorian Amazon, for instance, people usually live on the land that they farm, and while farm parcels are often sub-divided through sale or kinship ties, households are commonly linked to the farm in a 1 to 1 or a many to 1 relationship. LULC patterns on household farms in the Amazon are further influenced by socio-economic and demographic factors at the household level, but also through "neighborhood" associations and their regional and global contexts that further influence household decision-making about the use of the land as well as decisions to engage family members in off-farm employment in nearby communities or more distant places where remittances are an important part of household wealth and assets. In the Ecuadorian Amazon, labor sharing among nearby farm households is common, and the influence of towns on household behavior is also typical.

Distilling these various relationships and connections to "social spaces" is useful to understand the drivers of LULC change, examined through an assortment of methods, including, multi-level statistical models to link households to community characteristics, satellite image change-detections to address LULC trajectories of change at the household and regional levels, GIS approaches to describe the geographic accessibility of farm households to roads, communities, and other farms, and to assess the resource endowments of farms. In addition, spatial simulation models are used to examine population-environment interactions within the context of endogenous factors and exogenous forces that shape and re-shape pattern-process relations of people and land that influence subsequent LULC change patterns (Walsh et al. 2008b).

While there are still many issues that challenge the Land Change community, in the Galapagos Islands, international tourism is a major driver of LULC change. In 2007, UNESCO declared this World Heritage Site to be “at risk” from the direct and indirect effects of population migration, mostly from the mainland of Ecuador, fueled by migrants arriving in search of jobs in the burgeoning tourism industry. While temporary migrants, i.e., tourist, as well as migrants, arrive by airplane from the mainland of Ecuador to two entry points in the islands, they have traditionally accessed the islands from cruise ships and small yachts that travel the Galapagos Marine Reserve to visit designated sites, but increasingly tourists are relying upon placed-based recreation provided through an expanding hotel industry. Most of the products, such as food, water, gasoline, building materials, etc., arrive on cargo ships that are in perpetual motion between the Galapagos Islands and the mainland, and over 35 flights per week have created, in essence, a “land-bridge” to the islands.

Among the many challenges cited by the UNESCO declaration was population migration from the mainland through “push” factors from the primary sending areas and the “pull” factors of the Galapagos economy through the higher paying jobs in the tourism industry. Finally, human use zones have been established on the 4-populated islands in the Galapagos, and, while, the Galapagos National Park comprises 97-percent of the land area of the archipelago, urbanization in the coastal towns and agriculture in the highlands serve to mediate LULC in both settings and in the surrounding National Park. A serious problem in the Galapagos associated with the human dimension is the invasive flora and fauna that are replacing native and endemic species and altering the compositional make-up and spatial structure of LULC patterns. Eradication programs have reduced the areal extent of invasive species, but the problem persists, leading to land abandonment in the agricultural highlands, densification of the coastal urban areas, and diffusion of invasive species into protected areas of the Park. As employment in agriculture diminishes with poor market integration and invasive species, other employment sectors expand, particularly tourism, but also fisheries, recently sport fishing, through the close coupling of social, terrestrial, and marine sub-systems in the islands.

Methods & Approaches

In our work, we are closely examining the source and destination of the migrant population from the primary sending areas on the Ecuadorian mainland to the Galapagos Islands. A satellite image-time series and Ecuadorian Census (Population & Agriculture) data are being integrated to examine migration patterns, land fragmentation, land degradation, and land suitability for LULC. For instance, on the remote sensing side, we are fusing MODIS with a Landsat/ASTER data set through down-scaling approaches to study phenological cycles and inter-annual shifts in LULC and changes in land productivity, as well as ecological metrics to describe the spatial organization of LULC and productivity patterns through time, particularly, land fragmentation as a “push” factor to out-migration. In the Galapagos, where farms are relatively small and land parcels are irregular in shape and size, we are fusing Hyperion hyper-spectral data, Advanced Land Imager multi-spectral data, and QuickBird hyper-spatial data to assess LULC composition and structure. We use a linear and non-linear mixture modeling approach to define LULC fractions on a pixel-by-pixel basis (Adams et al. 1995) for the 30-meter cells of Hyperion and ALI (Walsh et al. 2008a, c). Classified QuickBird imagery is used to define spectral endmembers through Object-Based Image Analysis (OBIA) techniques (Blaschke et al. 2001). Different image objects are represented at multiple scales simultaneously via a hierarchical network of homogenous image regions that contain information about the texture, shape, and spectral response patterns. ALOS PALSAR, Synthetic Aperture Radar data, is also being integrated to describe image texture and structural information to improve our

discrimination of similar LULC types and age/density indicators of invasive species. To assess the possible spread of invasive species as well as the expansion of pasture and cropland, we are examining a niche-based, ecological habitat model (MaxEnt – Maximum Entropy) to determine land suitability for LULC types (Phillips et al. 2006), given various terrain settings, biophysical conditions, and social-ecological interactions, including distance measures and social factors.

Finally, we are integrating the remote sensing imagery, Ecuadorian Census data, including Agricultural Census data, tourism data from the Park, and new social surveys of tourists within an Agent-Based Model (ABM) to examine the impacts of population migration, including tourism, on LULC, alternate household livelihood strategies involving employment in the agriculture, fisheries, and tourism sectors, and plausible scenarios of change that involve social and ecological dynamics on mapped and modeled LULC patterns as well as agent adaptation and implications of agent choices on model outcomes. Using virtual or simulated representations of the Galapagos Islands that retain key social and ecological characteristics as a "natural laboratory" (Miller et al. In Press), as well as the development of actual place-based ABMs, our goals are to (a) test pattern-process relations that involve population-environment interactions, (b) assess migration patterns to the islands and agriculture and urban dynamics, (c) consider the expansion and contraction of the areal extent of invasive species that influence the movement of people from farms to towns as well as livelihood choices, (d) examine the feedbacks among socioeconomic and demographic characteristics of individuals, households, and communities and the environment through spatial simulation models (Mena et al. In press), calibrated and validated through multiple approaches, many involve LULC change patterns mapped through remote sensing approaches.

Discussion & Conclusions

An integrated design is being used that is multi-thematic, multi-resolution, and rooted in the explicit union of demographic and geospatial data. The goal is to link people to the land that they influence, directly and indirectly, and to map and model LULC change trajectories and the social-ecological drivers of change. Satellite data and historical aerial photography provide context to the LULC change and to the migration patterns that affect the Amazon and the Galapagos. Leveraging data collected through standard (e.g., GPS coordinates linked to field transects, social surveys, and spectro-radiometer measures of the environment) and unconventional approaches (e.g., life histories of household members linked to LULC change patterns), we assess fuzzy and crisp accuracies of LULC classifications and path dependencies and process understanding of spatial simulation models. In short, we routinely borrow theories and practices from the social, natural, and spatial sciences to link data, test hypotheses, and interpret findings. Integrated remote sensing is vital to the research enterprise, but defining "social spaces" where people influence LULC in implicit and explicit ways is a fundamental challenge influenced by available data, data collection strategies, image analysis approaches, and the questions under study.

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