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EDITORIAL

Land change in the southern Yucatán: case studies in land change science

B. L. Turner II

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Abstract The southern Yucatán Peninsular Region project was designed from the outset as an integrative, multidisciplinary program of study examining tropical deforestation in the largest track of seasonal tropical forest remaining in Mexico and in which smallholder agriculture and a major biosphere reserve are juxtaposed in regard to land uses and covers. Treating land as a coupled human–environment system, the project joins the remote sensing, environmental, social, and modeling sciences in a way that is now recognized as land change science. This paper introduces the project, the study region, and six papers that explore some of the coupled system dynamics in the region. These include the sub-regional variation in deforestation, the pan-regional adoption or anticipation of cattle ranching, the emergence of divergent household agricultural and overall livelihood strategies, the roles of cultural and household histories in agricultural livelihood choices, the temporal intensification of swidden cultivation and its implications for forest species, and carbon stocks across cultivation units, including a new econometric modeling application to forecast changes in these stocks.

Keywords Yucatán · Tropical deforestation · Land change · Coupled human–environment systems

Land change science has emerged as a new lens on an old topic—the terrestrial consequences of people and environment interactions (Gutman et al. 2004; Lambin et al. 2003; Turner et al. 2007; Turner 2009). It was stimulated, in part, by the recognition of various international research and assessment programs that global environmental change and sustainability could not be addressed adequately, let alone projected into the future, without improved understanding of land-use and land-cover change, and that this change involves human–environment interactions operating through the land user and resources or natural capital used (Moran et al. 2004). To address these interactions fully, land change science attempts to integrate the environmental, social, and geographical information sciences, including remote sensing, and to treat the phenomenon in question, the land system and its change, as a coupled human–environment system (CHES; GLP 2005; MEA 2003).[1] Various parts of land change science observe, monitor, explain, model, and project land use and cover; these efforts include understanding the dynamics of the human and environmental subsystems, their societal and biophysical consequences, and the feedbacks of these consequences of the land system. Contributions to land change science arise in research otherwise labeled as or shared with ecology-resilience (e.g., Berkes et al. 1998; Daily 2002; DIVERSITAS 2002; MEA 2003; Tilman et al. 2002), climate change (Watson et al. 2000), resource economics (Irwin and Geoghegan 2001), vulnerability (Turner et al. 2003a), and political ecology (Turner and Robbins 2008), among others. As global environmental change reaches to sustainability science (Kates et al. 2001), land change science remains one of its foundational elements.

B. L. Turner II (✉)
School of the Geographical Sciences and Urban Planning, and School of Sustainability, Arizona State University, PO Box 875302, Tempe, AZ 85281-5302, USA
e-mail: Billie.L.Turner@asu.edu

[1] Various efforts underway use labels other than CHES. Other terms include the social-ecological system (SES; Folke et al. 2002) and coupled human–natural system (CHANS; Liu et al. 2007). Each label refers to the same subsystems and their interactions.

The southern Yucatán Peninsular Region (SYPR) project, on-going since 1997, was one of the first field-based research projects designed specifically to address most of the elements of land change science as well as anticipating the synthesis elements found in the Global Land Project (GLP (Global Land Project) 2005). The SYPR project originally set out to understand the land changes underway, largely deforestation and agricultural expansion, in terms of the human drivers of these changes, their ecosystem impacts, and the environmental feedbacks on the land uses (Turner et al. 2004). It did so through an integrative research program involving ecologists addressing forest and fauna dynamics, and nutrient cycling; geographers, land use history and change, remote sensing, intra-household and gender dynamics, and agent-based modeling; environmental-resource economists, household decision-making and land change models; and anthropologists, ethnicity and culture into household consideration. As the data mounted, the project began to examine both the biophysical and human consequences of the land changes underway (see below) and, more recently, synthesis activities, such as those addressing land system vulnerability to different types of shocks and stresses (Turner et al. 2003b), both societal and environmental, and the role of land architectures (i.e., kind, magnitude, and pattern of land uses and covers; Turner 2009) on the sustainability of the CHESs found there.

The southern Yucatán (SY) is a project-designated region of study comprising nearly 2,000 km^2 of southeastern Quintana Roo and southwestern Campeche, Mexico. That portion of Campeche includes all of the *municipio* (municipality) of Calakmul. The SY matches the north–south boundaries of the Calakmul Biosphere Reserve (CBR) and the east–west dimensions of the uplands or *meseta* (>150 m elevation) that form the spine of the Yucatán Peninsula (Fig. 1).

The region was selected for study because it was and remains a development frontier in which Mexico placed its largest seasonal tropical forest reserve, the CBR (Primack et al. 1998). Established in 1989, the reserve was preceded by the establishment of a large number of *ejidos* (communally owned farming settlements and lands), especially with the completion in the late 1960s of an east–west highway that connects the SY to remainder of Yucatán and Mexico. The human population of the SY jumped from 2,500 in 1960 to 37,195 in 2000 (INEGI 2000), the land pressures of which registered the region as a hotspot of tropical deforestation (Achard et al. 1998; Trejo and Dirzo 2000). The SY represented then and remains now an interesting land-change study in which the needs of a growing number of smallholder farmers to cut forests for agriculture, legally so around and within parts of the CBR, runs counter to the subsequent efforts to maintain the older

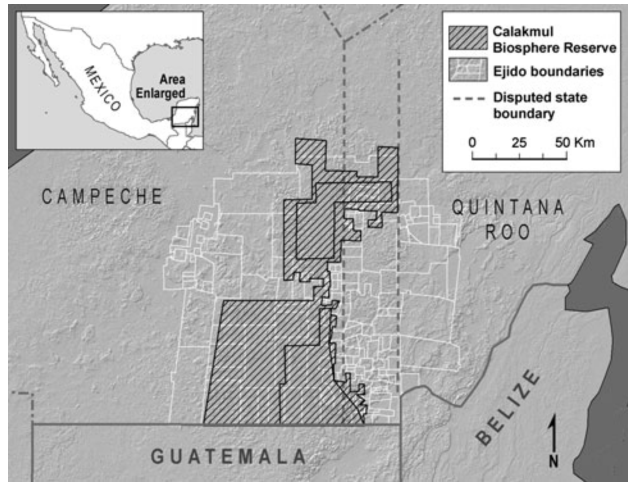

Fig. 1 The southern Yucatán Peninsular Region (SYPR) Project Assessment and Calakmul Biosphere Reserve Boundaries. Note that the *ejido* (settlement) boundaries mark all land units fully within the SYPR defined study region (see text)

growth forests of CBR for their carbon, biotic diversity, and role in maintaining ecosystem functions (Vester et al. 2007). The potential ramifications increased as the CBR became a pivotal part of the MesoAmerican Biological Corridor, designed to maintain the movement of biota across the peninsula and Central America (Miller et al. 2001; Riveria et al. 2002). Finally, owing to past work on ancient land uses and covers in the SY (e.g., Turner 1974; 1983), the SYPR project is informed by a long temporal dimension for its assessments that many other tropical forest studies are not.

The SY is a karstic upland dominated by a seasonal tropical forest ecocline that connects the xeric forests of the north of the peninsula with the humid forests of Petén, Guatemala and Belize. The forests of this ecocline, corresponding to a 900 to 1,400 mm north–south increase in annual mean precipitation, are marked more by their stature, seasonal leaf loss, and species abundance than by major changes in species present (Díaz Gallegos and Garcías 2002; Lawrence et al. 2004; Vester et al. 2007). They grow in shallow redzinas (troporendolls), typically 50–70 cm in depth. Interspersed among the uplands are solution sinks or poljes (locally, *bajos*) filled with montmorillonite clays that collect water during the wet season and hurricanes. The shallow, better drained *bajos* retain short-statured forests, sharing many species with the uplands. The deeper, less well drained sinks maintain grasses, marshes, and shallow *lagunas*. A few former rice and (current) cattle projects were/are located in *bajos*; for the most part, however, smallholder farmers avoid *bajos* proper and focus attention to upland cultivation.

While a few *ejidos* in the SY were created previous to 1960, most were established subsequent to that date. Many of these landholdings were taken by formerly landless farmers, especially from Veracruz and Tabasco, some with experience in commercial agriculture (Klepeis 2004; Gurri, this issue). Others were settled by subsistence farmers escaping conflict, especially from Chiapas. Initially supported by state-purchases of maize (corn), subsequent neoliberal economic reforms made direct payments to smallholders to intensify production, although in practice non-intensive cultivation was also supported. These monies were used for many purposes, including pasture creation (Klepeis and Vance 2003). Other farmers shifted to commercial jalapeño (chili) production, which proved to offer the highest potential reward of any crop but also held the highest level of risk owing to sensitivity of chili to hurricanes, drought, and disease-pests as well as to the ephemeral market controlled by intermediaries (Keys 2005; Keys and Roy Chowdhury 2006).

On average, operating under a semi-subsistence-semi-commercial production logic (Abizaid and Coomes 2004; Vance and Geoghegan 2004; Roy Chowdhury and Turner 2006), these farmers cut more than 65,000 ha of older growth, upland forest previous to 2000 (Rueda this volume). Subsequently and in response to multiple factors, smallholders appear to be cultivating extant opened lands by decreasing the length of fallow to around 6 years (Schmook, this issue). In the face of structural changes in the Mexican and regional economy (Schmook and Vance 2009), smallholders maintain elements of subsistence cultivation (Alayón-Gamboa and Gurri-García 2008) and are diversifying their household income sources, including increased investment in pasture (Busch 2008) and male-labor migration to the U.S. (Radel and Schmook 2008; Schmook and Radel 2008; Radel et al., this volume). These and other dynamics engender different livelihood strategies which have been variously clustered and analyzed (Gurri-Garcia, this volume; Roy Chowdhury 2010).

The initial expansion of agriculture and its subsequent intensification has generated various environmental feedbacks (Turner 2009). Propagated by persistent burning throughout the SY, an invasive species of bracken fern has taken over considerable areas of opened land (Schneider 2004; Schneider and Geoghegan 2006). The loss of forest per se, as well as the current cultivation practices, has drawn-down available soil phosphorous, which appears to be the limiting nutrient in the system (Lawrence et al. 2007), and as much as 36% of combined aboveground and soil carbon is lost with the cutting of mature forests (Eaton and Lawrence 2009; Diekman, Lawrence and Okin 2007). In addition, farmers remark that total rainfall is decreasing in the SY, an observation supported by what little systematic precipitation data exist for the region (Vester et al. 2007). The loss of evapotranspiration and increased temperatures created by opened lands and successional forests may be at play here, as suggested by research in Amazonia (Nobre et al. 1991). Finally, while the CBR may mimic well the proportion of forests types in the SY previous to substantial immigration to the area, the amount of disturbance surrounding the core of the reserve and the opened lands along the east–west highway and a newer north–south road, essentially cutting the core-buffer areas of reserve into quadrants, raises flags about the movement of biota across the ecocline (Vester et al. 2007).

This overview only scratches the surface of the range of research undertaken by the SYPR project, which also includes detailed land classifications (Schmook et al. 2011), environmental work (biotic diversity, forest structure, nutrient cycling—see above) and spatially explicit land modeling, both econometric and agent-based in kind (Geoghegan et al. 2005; Manson and Evans 2007; Parker et al. 2003). This special feature presents some of the more recent studies undertaken by SYPR project, including its cooperation with other units and individuals by sharing data and funding to derive the data. While the studies draw variously on remote sensing and environmental data and employ a range of approaches in problem formation and solution, each examines household or community impacts on forests and agriculture and/or responses to the regional dynamics affecting decisions regarding land change.

Land change research, by definition, must establish the land-use and -cover changes in question, commonly reported by the full area of the study. Rueda (this volume) employs project evidence to address "sub-study area" variance in land changes. Focusing on *ejido* type, she finds the variance in the rates and patterns of change to be significant and explained by land holdings, age, population change, and location along the regional precipitation gradient. Busch and Geoghegan (this volume) return to the pan-SYPR scale of analysis to address the increasing prevalence of pasture creation throughout the study region. Based on econometric analysis of detailed household survey data, they test the proposition that pasture planting is a land-use decision made in the face of resource constraints and economic incentives in what they describe as a "hollow frontier"—one in which economic development appears muted but deforested areas remain abundant. The major constraint at play is household labor, and cattle have relatively lower labor costs than, for example, commercial chili cultivation.

Two different household survey-based studies from the SY provide complementary results regarding the trajectory of household cultivation decisions. Radel, Schmook and Roy Chowdhury (this volume), group 200 households from across the region according to their agricultural activities and employ statistical variance analyses to examine socioeconomic differences among households and changes in their agricultural production strategies and land-cover impacts from 1997 to 2003. Their analyses demonstrate that increasing numbers of households were withdrawing from core agricultural activities at the same time that other households are intensifying and/or commercializing production, often via cattle ranching and pasture establishment. These trends suggest regional land changes, consistent with the Busch–Geoghegan hollow frontier theme, that include a possible forest transition concurrent with the growth of cattle ranching. Gurri (this volume) examines 499 households and identifies two types of household agricultural orientations by way of statistical analysis: those that remain largely subsistence oriented and those that are investing significantly in commercial cultivation. He interprets the former as subsistence farmers before migrating to the area, and the latter as having had little agricultural experience but were set on making agriculture their business in migrating to the SY. It is not yet clear if the geographical organization of the agricultural household trends and types identified in the two studies in question help explain the *ejido*-level land-change variances explored by Rueda (this volume). Likewise, the SYPR project has yet to determine if the current economic recession in the United States has altered male out-migration sufficiently to affect the land-cover trends reported here.

The last two studies link household survey and environmental data to address species diversity on disturbed (formerly cultivated) lands and carbon dynamics. Schmook (this volume) documents, for the first time, the recent changes in the frequency of cultivation by household and the presence of younger and less species diverse vegetation growth on lands incurring temporal intensification (reduced crop-fallow cycles). This last finding is consistent with the project's work demonstrating loss in available soil phosphorous and carbon storage among disturbed forests in the region. Finally, Geoghegan et al. (this volume)—an economist, ecologist and a geographer—provide a novel application of an econometric model that links detailed land-cover classes for agricultural *ejidos* with carbon data for each class, permitting an assessment of carbon stocks by category of forest. They link satellite data land classes in a multinomial logit model that estimates the probability of different land-covers in the future, thus holding the potential to estimate future carbon stocks under different economic and policy scenarios. The model, therefore, offers one approach applicable for use in proposal that seek to pay for environmental services and maintenance of forests.

The SYPR project in its original formation is giving way to complementary projects administered by its former members. For example, EDGY (Environmental Disturbance in Greater Yucatan) examines the role of hurricanes—a persistence disturbance on the forests of the SY—on ecosystems and people (http://landchange.rutgers.edu/). This and other activities spinning off the SYPR project retain the focus of land change science: to use the CHES approach as a means to understand the dynamics between the environmental and human subsystems capture in land cover and land use interactions.

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