Reg Environ Change (2010) 10:233–246
DOI 10.1007/s10113-010-0128-2

ORIGINAL ARTICLE

Shifting maize cultivation and secondary vegetation in the Southern Yucatán: successional forest impacts of temporal intensification

Birgit Schmook

Received: 11 February 2010 / Accepted: 7 May 2010 / Published online: 26 May 2010

Abstract Shifting cultivation around the Calakmul Biosphere Reserve of Mexico, part of the Mesoamerican Biological Corridor, appears to be intensifying temporally through reductions in crop–fallow cycles, with potential impacts on species diversity in the regenerating forest patches surrounding the reserve. This paper documents the temporal intensity of shifting maize cultivation in the region and links it to the species diversity found in secondary vegetation of different ages following different crop–fallow cycles. It finds that younger secondary growth, which is increasing under intensification, has less diversity in species composition. Simultaneously, the concentration of cultivation practices appears to foster more patches in older and more species-diverse vegetation. The implications for the preservation of the region's forest remain uncertain, however, given the spatial concentration of open lands along two key axes, one which dissects the reserve.

Keywords Seasonally dry tropical forests · Shifting cultivation · Agricultural intensification · Calakmul Biosphere Reserve · Biodiversity

Introduction

Estimates of the number of shifting cultivators globally range from 37 to 1,000 million (Mertz et al. 2009), the majority of which occupies tropical dry forests (Álvarez-Yépiz et al. 2008; Burgos and Maass 2004; Murphy and Lugo 1986a; Romero-Duque et al. 2007). In the face of increasing land pressures, especially on lands surrounding biological reserves (Figueroa and Sánchez-Cordero 2008; Lawrence et al. 2007; Wittemyer et al. 2008), concerns are raised about the efficacy of shifting cultivation in terms of its potential role in the loss of biotic diversity and ecosystem function (González-Iturbe et al. 2002; MEA 2005; Ochoa-Gaona et al. 2007).

To date, much attention has been paid to the scale of deforestation and the ecological consequences of the total land area under shifting cultivation (Brown and Schreckenberg 1998; Fujisaka et al. 1996). Much less attention has been given to the temporal dimension of shifting cultivation (i.e., repeated crop–fallow cycles) on secondary vegetation and its consequences on biodiversity and related environmental services (Sheil 2001). A notable exception exists for the humid forests in the Lacandon region in Chiapas (Mexico), where Ochoa-Gaona et al. (2007) found that secondary vegetation derived from low-intensity and low-frequency shifting cultivation cushioned the effects of fragmentation in agricultural areas and favored dispersal and establishment of native flora. In contrast, secondary succession in areas with decreasing fallow cycles displayed a decrease in plant diversity. Given the importance of understanding the land-use patterns in areas adjacent to or within biological reserves (DeFries et al. 2007; Figueroa and Sánchez-Cordero 2008) and the need to understand sustainable land architectures for tropical forests in general (Turner 2009), the impacts of increased cropping frequencies on biodiversity and ecological functioning warrant more attention.

In the southern Yucatán (SY) region of Mexico—defined as the southwestern portion of Quintana Roo state and southeastern portion of Campeche state—shifting cultivation is intensifying and the area under pasture is expanding (see Busch and Geoghegan, and Turner, this

---

B. Schmook (✉)
El Colegio de la Frontera Sur, Av. del Centenario Km 5.5,
C.P. 77900 Chetumal, Quintana Roo, Mexico
e-mail: bschmook@ecosur.mx

issue). This area lies around and within the Calakmul Biosphere Reserve (CBR), part of the Mesoamerican Biological Corridor (MBC). The combination of increasing numbers of farmers, state-mandated protection of primary forests, structural adjustment policies negatively affecting producer prices for basic staples, and expanding engagement in off-farm employment has led to an increase in cropping frequency in what is locally called *milpa* cultivation, a shifting cultivation system focused on maize, often intercropped with beans and squash and in some cases, incorporates chili in the cycle of land-use. In the 1960s, this system may have operated on as much as a 25-year fallow cycle; today that cycle has been reduced to 10 years or less (Klepeis et al. 2004). In many cases, multiple but much shorter crop–fallow cycles take place on the same parcel of land (Lawrence et al. 2007). This intensification in cultivation has not generated any significant increase in agricultural production which, for the most part, has not been accompanied by such inputs as fertilizers.

The research presented here asks: What are the impacts of crop–fallow cycles in shifting cultivation on the character of secondary forests in the SY? I address it by documenting current cropping frequencies and the species richness, diversity, and evenness in successional forests for parcels throughout the SY that are part of a shifting cultivation system. A series of quantitative tests examine the links between different crop–fallow cycles and three ecological measures. These links are particularly important because the area under study lies within the jurisdiction of the CBR and MBC (Vester et al. 2007). The reserve and corridor management is dedicated to preservation of biotic diversity, which includes the movement of biota along the ecocline of the SY, while farmers seek to improve their well being, which includes maintaining their claims to lands that maintain both successional and older growth forests.

Background on intensification and secondary vegetation

The intensification of shifting cultivation involves questions of reducing crop–fallow cycles, and the increasing frequency of cultivation affects the regeneration of vegetation once the fallow process begins or the land is abandoned. These two themes—crop–fallow reduction and secondary vegetation—warrant further elaboration.

Intensification in shifting cultivation

Shifting cultivation consists of cutting, drying and burning patches of woody vegetation to clear land for agricultural production (Ruthenberg 1980). Burning the vegetation temporarily eliminates weeds, releases the soil nutrient stock, replenishes nitrogen, and adds phosphorus, potassium, magnesium and manganese contained in the ash of the burned woody material (Chidumayo 1987; Ochoa-Gaona et al. 2007; Sánchez 1976; Wilken 1987). After one or more years of cultivation, the plot is left to fallow, allowing secondary forest to return and replenish soil nutrients. Forest re-growth also constitutes valuable capital, since secondary forest relatively quickly accumulates aboveground biomass, which increases the potential for carbon storage and provision of other environmental services (Álvarez-Yépiz et al. 2008). The secondary forest is eventually cut and the plot is brought back into cultivation (Pascual and Barbier 2006). In this way, shifting cultivation tends to be labor and input efficient, but over the crop–fallow cycle, the level of production per plot cultivated is relatively low (Turner and Brush 1987).

Agricultural intensification is defined in a number of ways, all of which are intended to address the increase in land productivity through increases in inputs of any form (Boserup 1965, 1988; Brookfield 1984, 1993; Doolittle 1984; McConnel and Keys 2005; Netting 1993; Ruthenberg 1980; Turner and Doolittle 1978; Turner et al. 1977). A common intensification strategy among shifting cultivators involves increasing the cropping frequency by reducing the ratio of the fallow to the cultivation periods. As the fallow period declines, the application of inputs increases, such as the use of fertilizers, pesticides and more frequent weeding (Boserup 1965, 1988; Brookfield 1984; Doolittle 1984; McConnel and Keys 2005; Netting 1993; Ruthenberg 1980; Shriar 2000; Turner and Brush 1987; Turner and Doolittle 1978; Turner et al. 1977). Such steps are frequently, but not necessarily, taken because of increasing pressure on land generated by increasing demand for cultivation (Boserup 1965; Turner and Brush 1987).

Cropping frequency has been used as one measure of agricultural intensity for shifting agriculture (Boserup 1965; Joosten 1962; Ruthenberg 1980; Shriar 2000; Turner and Doolittle 1978). It refers to the length of time a parcel of land is cropped compared to the time it is left fallow. Such measures (e.g., the *R* value by Ruthenberg 1980), however, do not account for double cropping or two harvests per year from the same plot, which occurs in some shifting cultivation systems. For instance, in the SY, some farmers cultivate winter maize (*tornamil*) after the summer maize on the same plot in the same year (Roy Chowdhury and Turner 2006). To account for this double cropping, a measure developed by Turner and Doolittle (1978) is employed in this study: the number of harvests in one cultivation period is divided by the combined total number of years of fallow and cultivation. For example, if the entire cultivation cycle is 1:4 (one harvest in 1 year and 4 years of fallow), the cropping frequency is 0.20 (1 harvest divided by the 5 years of the entire cultivation cycle). If two crops are harvested in 1 year, followed by 4 years of fallow, the cropping frequency would be 0.40. Using this measure, data on cultivation and fallow periods for *milpa* cultivation reported by Eastmond and Faust (2006) for the state of Yucatán can be translated into cropping frequencies ranging from 0.06 to 0.38. At the high end, these values constitute some of the highest for shifting cultivation systems worldwide (Ruthenberg 1980).

Measuring cropping frequency can be further complicated by the simultaneous use of various crop–fallow cycle practices within a single household. This variance is ignored in many studies in which attention focuses on the crop–fallow cycle that prevails for the major or staple crop (Turner et al. 1977). Gleave (1996) criticizes this approach as masking critical variability across households and even within a single household that reflects management decisions and varying access to land within communal tenure systems (Ickowitz 2006). Different fallow and/or cropping lengths can also vary between crops, as in the case of maize or chili cultivation in the SY. Such variance is not a problem in this study because analysis is at the individual plot level.

Impact of increasing crop–fallow cycles on secondary vegetation

Regardless of its immediate or local importance, Murphy and Lugo (1986a) suggest that most shifting cultivation occurs in tropical dry forests, rather than in tropical humid forests. This is a reflection of human settlement preferences and, perhaps, the fact that tropical dry forest is of a generally smaller stature compared to the more humid tropical rain forests, rendering forest clearing easier. Additionally, dry forest soils tend to be more fertile than those of humid forests because less leaching occurs, and weeds and successional vegetation tend to be less aggressive (Murphy and Lugo 1995). Given this preference, secondary forests are expanding among dry forests, with implications for biodiversity, seed stocks, and soil nutrients (Álvarez-Yépiz et al. 2008; Brown and Lugo 1990; Burgos and Maass 2004; Daily et al. 2003; Foley et al. 2005; Romero-Duque et al. 2007; Vieira and Scariot 2006).

To date, studies have tended to focus on the changing properties of secondary forest as they are permitted to grow toward older growth status (Finegan 1996; Marín-Spiotta et al. 2007; Peña-Claros 2003; Pinard et al. 1999; Saldarriaga et al. 1988; Vester 1997). These studies indicate that secondary forests maintain differences in their structure and composition for long periods. For example, the Shannon–Wiener diversity index increases significantly in the first stages of succession, but subsequently this rate of increase slows (Marín-Spiotta et al. 2007; Saldarriaga et al. 1988) due to differences in regeneration patterns between species that are likely to colonize a recently disturbed area and those that require forest cover in order to colonize an area (Pinard et al. 1999; Vester 1997).

The qualities of secondary forests depend on the nature of prior disturbance, which is a function of fallow length, cultivation length, number of cropping cycles, and other management practices (Lawrence et al. 2005). Lawrence (2005) demonstrated that biomass and forest structure in Borneo are dependent upon the previous number of cultivation cycles. Further, in central Amazonia, Gehring et al. (2005) documented that the first cycle of re-growth had only minor effects on secondary vegetation biomass, but changed the structural characteristics if land-use intensity increased by extending the cultivation period.

Murphy and Lugo (1986a) report that succession in dry tropical forests is slower, in terms of plant growth and other developmental features, than in humid forests. The relative structural simplicity and small stature of dry forests and the predominance of coppicing within dry forests, however, foster conditions that favor recovery to a mature state more quickly than do humid forests. Coppicing is the primary regeneration mechanism that occurs in dry sites that have been cut but with stumps and roots remaining in place (Ewel 1977; Murphy and Lugo 1986b). A consequence of this practice is the very patchy development of dry forests in the early stages of succession and the development of a long-lived stage characterized by a large density of very small tree stems (Murphy and Lugo 1986b).

For the dry forests of the SY, Vester et al. (2007) found that stem density of small stems [<10 cm diameter at breast height (DBH) of 1.30 m] was much greater in young secondary forests (aged 2–10 years), and was especially pronounced in the 5–10 cm DBH range. Further, a larger percentage of large stems (>10 cm DBH) existed in the mature forest as opposed to older secondary forests. This difference was even clearer in the youngest secondary forests, where the density of large stems was 89% lower than in mature forests. Canopy heights displayed the same tendencies with young secondary forests being considerably lower. Maximum canopy height for all secondary forests was 40% lower than that of mature forest (14 vs. 23 m).

Studies examining the recovery of species composition reveal contrasting findings. While Brown and Lugo (1990) reported slow recovery, Pérez-Salicrup (2004) found that forest succession took place rapidly in the SY, with species composition indistinguishable from old-growth forests only 20–30 years after agricultural abandonment. This result was attributed to two possibilities: (a) former Maya occupancy fostered resilient, often re-sprouting tree species, and (b) the forests in question had only one cycle of cultivation and were still relatively close to mature forest seed sources. These hypotheses are challenged by Haug et al. (2003) who attribute the resilience of the forest system to the intermittent dry–humid cycles in the Yucatán Peninsula. Like Pérez-Salicrup, Lebrija-Trejos et al. (2008) indicate that initial forest succession is rapid in Nizanda, Oaxaca, with tree densities and coverage in the early stages comparable to those of a mature forest. Recovery in the diversity of species occurs slowly, however, starting from 30 years of land abandonment (Lebrija-Trejos et al. 2008).

Research design, data and methods

Data

Two sources of data are employed in this study: household survey data and species counts in secondary forest. The survey data were used to establish crop–fallow cycles and the age of secondary vegetation used in cultivation as well as information on cropping practices and the rationales for their use. A household survey was conducted in 2004 and 2005, which gathered data for the 2003 agricultural year (henceforth, the 2003 survey). This 2003 survey constituted a follow-up to a 1997 survey that employed a stratified two-stage cluster design. In this design, the SY was geographically divided into 11 strata with 1 *ejido* (a tenure unit or community akin to a village and its lands) randomly selected from each stratum. From the resulting 11 communities, 188 households were selected randomly based on an enumeration of official community members; the number of respondents per community was roughly proportional to the community's representation in the 11-community population. The 2003 survey returned to the same households selected in the 1997 survey. In 26 cases where the household no longer existed or was unwilling to participate, replacement households were selected randomly from the community in question. In addition, 34 households located within three new communities were added to the 2003 survey to capture the dynamics of the southern stratum of the SY where more of the newer and smaller communities reside. The new communities were randomly chosen from the list of communities located in this southern stratum. The 2003 survey included a total of 203 households.

The new survey was undertaken over 18 months by the author in collaboration with Chris Busch (see Busch and Geoghegan same issue) and three field assistants. The male head of the household was interviewed; if the male head was away (usually performing migrant labor), his wife or eldest son was consulted. Information was collected on the area cultivated, crop management, purchased inputs, and crop and fallow duration for all crops. This information was obtained for each of the plots cultivated by the household in the reference year. We also asked about the household's general fallow and cultivation periods, independent of a specific plot. Informants were also asked about their preferences for secondary vegetation and about the optimal age of secondary vegetation or old-growth forest to cut for cultivation. Only the most common categories of answers are addressed here, given space limitations. Non-standardized open-ended interviews with farmers were undertaken to determine their perception of the economic benefits of maize cultivation under current and past socio-economic conditions.

The cropping frequencies and their changes reported here are calculated and discussed primarily in terms of the principal subsistence crop grown in the SY, maize. The study on the impacts on secondary growth focuses exclusively on maize plots and considers the crop–fallow cycles employed on them. This focus on maize was made in order to control for household parcels that have been fertilized, a practice in commercial chili cultivation which may be added to rotations in shifting maize cultivation. The data on the impacts of maize cultivation were drawn from a total of 23 secondary vegetation plots sampled in several field campaigns in six communities that were part of the larger survey. Each of these communities was located adjacent to the CBR, and as a group covers the middle range (900–1,200 mm) of the precipitation gradient in the SY. The age of secondary vegetation plots was identified through extensive household interviews with participants of the household survey. Respondents identified vegetation ages according to four categories of years in fallow: 5–6, 9–10, 12–15 and 20 years. Previous work has determined that forests beyond 25 years are considered older growth, little of which is currently cut (Vester et al. 2007). Plot-age and land-use history were re-confirmed with secondary interviews before plot sampling. The 23 secondary vegetation plots belonged to 18 households.

Each of the secondary vegetation plots meets the condition that all previous land-uses were maize and that the original forest cover on the plot was selva mediana subperennifolia, as determined by Miranda and Hernández Xolocotzi (1963)—the dominant, upland forest type in this part of the SY ecocline (Pérez-Salicrup 2004; Vester et al. 2007)—and described by Turner (this issue). All sampled secondary vegetation plots were located in secondary forest stands of 1–1.5 ha. In the center of each stand, we established a 25 m × 25 m quadrat, and subdivided it into 5 m × 5 m^2 sub-plots to facilitate measurement. The sampling size of 625 m^2 was based on studies undertaken by Illsley and Hernández-Xolocotzi (1982), Sarukhán and Hernández Xolocotzi (1970), and Levy-Tacher (1990) that conclude that 500 m^2 is the minimum area to be sampled for early succession of 1–14 years, and that 625 m^2 was adequate surface area for this study.

DBH was recorded for all live, rooted trees > 10 cm DBH (diameter at breast height, 130 cm); these trees were marked in red. All individuals of DBH 5–10 cm were also marked and measured in a sub-quadrat of 10 m × 10 m. Species were identified by their common names with the help of local guides, and verified by various vegetation guides (Pennington and Sarukhán 1998; Sosa et al. 1985; Téllez-Valdés et al. 1982). If any discrepancy or question existed, we collected leaves, flowers, or fruits and identified them at the herbarium collection of El Colegio de la Frontera Sur-Unidad Chetumal. All trees meeting the DBH dimensions were included in the analysis.

Analysis

Cropping frequencies were calculated individually at the household plot or parcel level as suggested by Turner and Doolittle (1978), owing to potential variance in cropping strategy within a household. Basic statistics, *t* tests, ANOVAs and OLS (Ordinary Least Square) regressions for overall land-use and cover, area, and management of maize plots at the household level were performed. We also undertook a qualitative analysis of farmer's preferences for secondary vegetation versus older growth forest and the economic benefit of maize cultivation.

For statistical analysis, all 23 secondary plots were grouped according to the age of the vegetation and their cropping frequency. The values of cropping frequency ranged from 0.05 to 0.35. To simplify the analysis, we clustered the lower cropping frequencies (0.05–0.20) into group 1, and the higher frequencies (0.21–0.35) into group 2. The age of the secondary vegetation and clustered cropping frequencies was grouped, yielding five age–frequency categories, as follows: 5 (1), 5 (2), 10 (1), 15 (1) and 20 (1). The first figure is age and that in parenthesis is the cropping frequency group. Thus, 5 (1) constitutes a 5-year fallow vegetation in a low-frequency cycle, and 20 (1), a 20-year-old vegetation in the same frequency class. To detect statistically significant differences between the age-cropping frequency groups, we performed a one-way ANOVA with the Fisher test (95%) using Statgraphics 4.1.

Several measures of the character of successional growth were generated. For all of these measures, average measurement values are presented for each group to facilitate across-group comparisons. The number of families, genera, and species is reported for each of the five age–frequency groups. The five most important families accompanied by the number of species for each family in each of the five age–frequency groups are also provided. Additionally, importance values (IV) per age group (Sarukhán and Hernández Xolocotzi 1970) were calculated:

$$\begin{aligned}\text{Importance value (IV)} = {} & \text{relative abundance} \\ & + \text{relative frequency} \\ & + \text{relative dominance}\end{aligned}$$

Dominant species were those contributing at least 4% to the importance value of all species in each group.

To approximate the biomass contribution of tree species > 5 cm DBH, the density of individuals per ha and basal area were calculated. For basal area, the universal formula for calculating the surface of a circle was used.

Species richness (*d*) (Margalef 1958 in Odum 1985) was calculated as

$$d = (S - 1)/\log N$$

where S is the number of species and N is the number of individuals.

The Shannon–Wiener (H') index of species diversity is normally calculated using the generic formula:

$$H' = -\sum P_i \log 2P_i$$

where P_i is the number of individuals of each species divided by the total of individuals.

For this study, we used the converted formula to simplify the calculations:

$$H' = -\sum P_i 3.3219 \log(P_i).$$

To calculate evenness (E), according to Shannon–Wiener, it is necessary to first calculate maximum diversity ($H'_{\max} = \log 2S$, S = number of species).

The formula for evenness, therefore, is

$$E = H'/H_{\max}$$

Results

Land cover and use and cropping frequency

Households in the SY are land rich; on average they have access to 71.10 ± 41.71 ha (STD, standard deviation) of land (Table 1). Total land access per individual household ranges from a mean of 30.35 ± 13.41 ha in the most land pressured communities, to 117.90 ± 4.01 ha in the least land pressured one. Almost 50% of the household's land access, on average, is covered with older growth forest (i.e., >25 years). Nevertheless, secondary vegetation, especially early secondary vegetation (<10 years), occupies a substantial part of the land (15.15 ± 13.93 ha or ~21% of the land). The area with older secondary vegetation (older than 10 years) is substantially lower (4.43 ± 16.01 ha).

Excluding pasture, most households ($N = 138$, 77.5%) cultivated only one plot per year; 36 households (20.2%), two plots; three households (1.7%), three plots; and one managed six cultivated plots. In total, 225 contiguous plots

Table 1 Average land access and land-use distribution per household at the community and sample level in hectares

	El Refugio	Centauro del Norte	Álvaro Obregón	Nuevo Becar	X-Bonil	Nicolás Bravo	La Lucha	Tomas Garrido	Arroyo Negro	Chan Laguna	Km. 120	Alacranes	Caña Brava	Ricardo Payro	Total
N	9	18	21	17	23	22	6	15	13	14	11	9	12	13	203
Household land access															
Mean	67.33	103.33	46.17	41.53	86.43	110.2	50.67	109.93	30.35	34.59	117.91	66.5	55.56	37.38	71.1
Median	60	100	27	40	100	100	60	107	28	36.5	116	70	50	40	60
STD	20.52	26.92	57.32	20.88	42.77	23.78	14.85	22.55	13.41	12.4	4.01	7.68	14.18	14.87	41.71
Secondary vegetation $<$ 5 years															
Mean	3.89	8.06	4.48	4.26	7.86	5.93	10.33	4.37	9.71	5.79	7.75	17.31	13.71	5.54	7.24
Median	3.5	7	4	3	5.25	4	6.5	2	6.5	3.5	6	12	13.5	4	5
STD	2.79	4.7	3.96	5.54	8.56	7.65	9.48	6.27	12.7	7.09	5.25	13.23	12.14	5.32	8.18
Secondary vegetation 5–10 years															
Mean	11.39	5.17	4.86	8.04	13.1	14.18	4.5	6.13	4.38	4.14	5.64	8.61	8.21	6.62	7.91
Median	8	5	1	5	5	7.25	1.5	5	1	1	3	8	6.5	4	4.25
STD	10.43	4.6	7.25	8.94	17.47	22.61	5.65	6.7	4.86	6.02	5.22	7.56	7.9	6.12	11.54
Secondary vegetation 10–15 years															
Mean	3.78	0.94	6.76	1.88	1.52	2.36	2.5	4.87	3.96	0.36	8	0.81	1.67	1.77	2.93
Median	0	0	0	0	0	0	2	0	0	0	5	0	0	0	0
STD	10.26	2.88	21.69	5.09	6.29	5.57	2.74	12.22	9.67	1.34	11.32	2.15	3.26	4.27	9.5
Secondary vegetation 15–20 years															
Mean	2.22	0.22	3.29	1.12	0	1.18	0	2.47	0	0	0	0.56	0	0	0.89
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
STD	6.67	0.94	11.27	4.61	0	3.94	0	6.08	0	0	0	1.67	0	0	4.65
Secondary vegetation 20–25 years															
Mean	0	0	2.38	0	1.65	0.45	0	0	0	0	2	0.56	0	0	0.62
Median	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
STD	0	0	10.91	0	7.92	2.13	0	0	0	0	6.63	1.67	0	0	4.71
Old-growth forest															
Mean	38.06	80.89	17.1	13.71	41.26	45.84	28.25	65.12	5.31	2.07	87.18	23.28	21.58	5.92	34.96
Median	34	79	7	10	40	50	32.5	72	0	0.5	95	20	20	4	26
STD	14.95	27.54	20.54	14.56	30.22	32.12	15.61	23.49	8.51	2.76	25.89	13.61	15.57	8.59	33.79
Pasture															
Mean	3.22	2.22	2.07	5.29	15.09	24.45	1	22.63	1.35	19.66	1.36	6.44	3	12.69	9.85
Median	0	0.5	0	0	10	3	0	22	0	18.5	0	3	2.5	3	2
STD	5.56	3.22	5.71	8.39	17.71	37.49	1.67	19.74	2.84	12.66	3.26	6.97	3.25	19.91	18.18
Crops															
Mean	3.22	3.97	3.07	3.79	3.87	7.9	2.13	3.27	4.94	2.43	3.82	4.5	4.81	2.19	4.04
Median	3	3.75	2	4	4	4.5	2.25	3	4	1	3	4.5	3.63	2	3
STD	1.42	2.28	2.11	2.33	3.89	9.35	1.36	2.53	3.17	2.95	4.26	1.2	2.96	2.03	4.23

were farmed by 178 households. 25 of the 203 households in the sample had no crops or only pasture in the reference year. A few (8) of these plots were cultivated with crops (e.g., papaya) other than maize or chili. Households often, but not always, divide their plots to accommodate both maize and chili in the same cropping period in order to reduce travel time. A total of 60 plots were divided in this way. Adding the 60 maize sub-plots to the 130 main maize plots, a total of 190 maize plots were recorded. Information is sufficiently complete to calculate cropping frequencies for 182 of these plots. An overwhelming 83% of maize plots were taken from secondary growth, and only 17% from older growth forest.

In 2003, a total of 175 (86.20%) out of 203 households cultivated maize (Table 2). In 1997, all 188 households sampled cultivated maize. A *t* test of difference between the area of maize cultivated over all sampled households in 1997 and 2003 reveals that maize was grown in a significantly smaller area in 2003 than in 1997 (3.28 vs. 4.51 ha; $P = 0.002$). Differences by community exist. In five, all

Table 2 Basics statistics on shifting maize cultivation

	El Refugio	Centauro del Norte	Álvaro Obregón	Nuevo Becar	X-Bonil	Nicolás Bravo	La Lucha	Tomas Garrido	Arroyo Negro	Chan Laguna	Km. 120	Alacranes	Caña Brava	Ricardo Payro	Total
Farmers cultivating maize															
N	9	16	21	15	19	19	6	12	13	7	9	9	12	8	175
Missing	0	2	0	2	4	3	0	3	0	7	2	0	0	5	28
Area in ha with maize															
Mean	2.5	2.84	2.83	3.66	4.44	7.60	2.04	2.91	4.26	4.5	3.33	3.05	3.62	2.5	3.81
Median	3	2.5	2	3	4	4	2	3	3	4.5	2	3	3	2.25	3
STD	0.70	1.56	1.74	1.54	3.79	8.11	1.34	1.44	2.94	2.06	3.31	0.95	2.12	0.80	3.61
Maize harvested per hectare															
Mean	527.78	482.3	264.921	396	216.55	499.638	432.778	1,107.6	667.39	478.57	155.6	312.96	213.1	711.25	445.46
Median	400	413.3	150	380	111.67	461.539	400	1,000	500	500	150	325	158.3	720	333.33
STD	408.76	402.9	269.708	244.63	239.02	471.258	212.084	784.54	461.05	289.91	126.9	193.83	220.7	646.158	448
Number and percent of households using chemical fertilizers in maize (dummy)															
N of HH	2	3	0	4	3	5	0	4	0	1	1	0	1	0	24
Percent	22.22	18.75	0.00	26.67	15.79	26.32	0.00	33.33	0.00	14.29	11.11	0.00	8.33	0.00	13.71
Number and percent of households applying chemical pest control maize (dummy)															
N of HH	1	4	1	1	1	3	0	1	0	1	0	0	3	0	16
Percent	11.11	25.00	4.76	6.67	5.26	15.79	0.00	8.33	0.00	14.29	0.00	0.00	25.00	0.00	9.14
Number and percent of households intercropping maize (dummy)															
N of HH	4	14	12	5	11	5	2	4	11	3	6	5	5	0	87
Percent	44.44	87.50	57.14	33.33	57.89	26.32	33.33	33.33	84.62	42.86	66.67	55.56	41.67	0.00	49.71
Hectares winter maize (*tornamil*)															
N	9	3	3	5	5	4	1	7	6	2	0	4	7	2	52
Mean	1.16	1.66	0.75	2.2	1.55	1.25	0.25	2	1.5	3		1.62	1.35	2.5	1.62
Median	1	2	0.75	2	2	1	0.25	2	1.5	3		1.5	1	2.5	1.5
STD	0.76	0.57	0.25	1.64	0.87	0.5		0.81	0.44	1.41		1.10	0.74	0.70	0.94
Cropping frequencies for maize parcels[a]															
N	8	14	15	15	18	14	4	7	13	7	9	10	13	4	151
Mean	0.32	0.45	0.33	0.25	0.41	0.33	0.48	0.35	0.24	0.31	0.28	0.27	0.29	0.22	0.32
STD	0.16	0.20	0.17	0.14	0.13	0.21	0.19	0.18	0.14	0.19	0.13	0.06	0.13	0.04	0.16

[a] Cropping frequencies are based on plot-level information, not on household level information, as the rest of the data provided in this table

households interviewed cultivated maize; in two, only 40–50% cultivated maize. The average area cultivated per household with maize did not vary much among the communities, averaging 3.81 ± 3.61 ha in which the highest community average was 7.60 ± 8.11 ha.

Chemical inputs such as fertilizers were used on maize plots by only 24 (14%) households. In five communities, no household reported its use; the highest usage was 33% of the households in one community. Pesticides were used less frequently. Only 16 households (9%) reported having used pesticides. About 50% of the households intercropped maize and beans, and 52 households in the 14 *communities* cultivated winter maize (*tornamil*).

The average cropping frequency for maize plots in the sample was 0.32 ± 0.16. These plots were cultivated with maize only in the reference year of the survey (2003). The previous or following crop was or was projected to be maize only, according to the owners of the plot. This cycle was achieved by 3.12 ± 3.68 years of cultivation and 5.88 ± 4.18 years of fallow. Average cropping frequencies for all swidden plots ranged from 0.21 ± 0.04 to 0.47 ± 0.18 across the communities, with no significant differences among communities based on ANOVA. Surprisingly, no significant relation exists between land access and cropping frequencies at the community level ($R^2 = 0.029$, $P = 0.559$) or household level ($R^2 = 0.004$, $P = 0.368$).

Only 34% of the 182 valid respondents said they managed different fallow lengths on different plots. 143 (71.1%) households had cleared secondary vegetation for cultivation, while 58 households (28.9%, $N = 201$) cleared older growth forest for cultivation. The expressed preferred age of secondary vegetation to cut was 5.92 ± 2.87 years ($N = 126$, median 5 years). This stated preference is supported by the observed data generated in this study.

Tree species diversity in secondary vegetation

During field sampling, vouchers from 718 individuals > 5 cm DBH in the 23 secondary vegetation plots were collected. Floristic composition consisted of 75 species distributed over 60 genera and 29 families.

Table 3 displays the distribution of species, genera, and families over all five secondary age–frequency classes. As the age of the secondary vegetation increases, so does the number of species, genera and families, with the exception of the 20-year-old secondary vegetation. The lower diversity numbers in the 20-year-old secondary vegetation are possibly attributable to the lower number of plots compared to the rest of the groups. No substantial differences in the number of species, genera and families were found between 5 (1) and 5 (2) regimes.

Five families account for more than 50% of all species across all groups (Table 4). Fabaceae, with 22 species, is the most abundant family in all groups, followed by Moraceae, which is specifically abundant in 10 (1), 15 (1) and 20 (1). Sapotaceae is among the most abundant families in 5 (2), 10 (1) and 15 (1).

The importance values for the most important species in each of the five age–frequency classes are listed in Table 5. In group 5 (1), 8 out of 17 species accounted for 85% of the importance value, and in group 5 (2), 8 out of 16 accounted for almost 80%. In group 10 (1), more than 45 species were found, but only 9 reached the 4% threshold; in group 15 (1) seven species out of 51 reached the 4% threshold.

Tree densities and basal area in the two 5-year-old secondary vegetation age–frequency classes were low, as not many trees met the 5 cm DBH threshold, and the ones that did had small diameters (average diameter 7.11 ± 2.05 cm for 5 (1) and 7.13 ± 2.10 cm for 5 (2)) (Fig. 1). There were statistically significant increases in stem density between the two early secondary vegetation groups and the remaining groups, but not among the 10-, 15- and 20-year-old secondary vegetation groups. The difference in basal area between both of the two early secondary vegetation groups 5 (1) and 5 (2) and the remaining three groups was statistically significant.

All three measures of diversity increased as secondary vegetation matured (Fig. 2). With regard to species richness, a statistically significant difference exists between group 5 (1) and the 20-year-old class, but not between group 5 (1) and the 10- and 15-year-old classes. Significant differences also existed between the other early age–

Table 3 Grouping of the 23 plots according to the age of secondary vegetation, cropping frequency class, taxonomic level and measures of average species richness, diversity, evenness and density

Groups secondary vegetation age-cropping frequency class	Secondary vegetation age range in years	Range of cropping frequency in age group	Cropping frequency class	Taxonomic level				Measure (averages)				
				Number of plots	Families	Genera	Species	Shannon[a]	Simpson[a]	$H^{a}_{\max}$	Evenness[a]	Density (ind/ha)[a]
5 (1)	5–6	0.090.17	1	5	11	16	17	1.86 ± 0.79 ab	0.63 ± 0.24 b	2.28 ± 0.81 ab	0.75 ± 0.19 b	1,223.20 ± 420.63 a
5 (2)	5	0.022–0.35	2	5	11	15	16	1.04 ± 1.18 a	0.34 ± 0.35 a	1.40 ± 1.52 a	0.44 ± 0.41 a	1,346.40 ± 143.11 a
10 (1)	9–10	0.09	1	6	23	41	45	2.41 ± 0.40 b	0.74 ± 0.07 b	3.02 ± 0.49 bc	0.79 ± 0.09 b	2,650.17 ± 1,200.22 b
15 (1)	12–15	0.06–0.13	1	4	24	43	51	2.45 ± 0.48 b	0.72 ± 0.12 b	3.10 ± 0.49 bc	0.75 ± 0.13 ab	2,785.50 ± 415.69 b
20 (1)	20	0.05–0.09	1	3	18	26	32	2.71 ± 0.60 b	0.76 ± 0.13 b	3.84 ± 0.15 c	0.70 ± 0.13 ab	3,422.67 ± 980.53 b
								0.03[b]	0.04[b]	0.01[b]	0.15[b]	0.02[b]
								0.08[c]	0.26[c]	0.02[c]	0.48[c]	0.06[c]
Total	5–20	0.05–0.35	1–2	23	29	60	75					

Different letters (a, b, c) indicate significant statistical differences between the group's result of one-way ANOVA ($P < 0.05$)

[a] ±STD

[b] Fisher test

[c] Kruskal–Wallis test

Table 4 The five most species-rich plant families and number of species in each family in the five secondary vegetation age-cropping frequency groups and percent contribution to overall number of species in each group

5 (1)	5 (2)	10 (1)	15 (1)	20 (1)	Total
Fabaceae (7)	*Fabaceae* (3)	*Fabaceae* (15)	*Fabaceae* (13)	*Fabaceae* (10)	*Fabaceae* (22)
Burseraceae (1)	*Polygonaceae* (3)	*Sapotaceae* (4)	*Sapotaceae* (4)	*Euphorbiaceae* (3)	*Moraceae* (6)
Apocynaceae (1)	*Sapotaceae* (2)	*Moraceae* (3)	*Moraceae* (4)	*Polygonaceae* (2)	*Sapotaceae* (4)
Verbenaceae (1)	*Burseraceae* (1)	*Rubiaceae* (3)	*Rubiaceae* (3)	*Moraceae* (2)	*Polygonaceae* (4)
Ulmaceae (1)	*Apocynaceae* (1)	*Polygonaceae* (2)	*Euphorbiaceae* (3)	*Verbenaceae* (2)	*Euphorbiaceae* (4)
64.71%	62.5%	58.70%	54.00%	59.38%	53.33%
3.63 ± 1.42[a] (ab)	2.23 ± 2.56[a] (a)	5.10 ± 1.31[a] (b)	5.40 ± 0.84[a] (bc)	7.74 ± 1.30[a] (c)	

Number of species in each family is in parentheses. Fisher test = 0.00, Kruskal–Wallis test = 0.01

Different letters (a, b, c) indicate significant statistical differences between the group's result of one-way ANOVA ($P < 0.05$)

[a] Species richness ± STD

Table 5 Most important species in the five secondary age-cropping frequency groups

5 (1)	IV[a]	5 (2)	IV[a]	10 (1)	IV[a]	15 (1)	IV[a]	20 (1)	IV[a]
Bursera simaruba	(33.99)	*Hampea trilobata*	(16.98)	*Bursera simaruba*	(16.61)	*Piscidia piscipula*	(10.34)	*Croton arboreus*	(16.86)
Thevetia gaumeri	(12.20)	*Lysiloma latisiliquum*	(15.00)	*Croton arboreus*	(11.82)	*Croton arboreus*	(9.99)	*Bursera simaruba*	(12.31)
Lysiloma latisiliquum	(11.63)	*Bursera simaruba*	(12.97)	*Thevetia gaumeri*	(6.45)	*Bursera simaruba*	(8.38)	*Croton sp.* (Linneo, 1753)	(7.70)
Cecropia peltata	(7.70)	*Gymnopodium floribundum*	(11.68)	*Acacia dolichostachya*	(5.05)	*Lonchocarpus xuul*	(8.30)	*Colubrina sp.* (Rich ex Brongn 1826)	(6.83)
Vitex gaumeri	(6.16)	*Lonchocarpus rugosus*	(8.29)	*Piscidia piscipula*	(4.77)	*Ficus sp* (Linneo, 1753)	(7.79)	*Piscidia piscipula*	(5.95)
Platymiscium yucatanum	(4.75)	*Vitex gaumeri*	(4.99)	*Hampea trilobata*	(4.51)	*Thevetia gaumeri*	(6.38)	*Lysiloma latisiliquum*	(5.94)
Piscidia piscipula	(4.74)	*Sideroxylon salicifolium*	(4.50)	*Pouteria campechiana*	(4.31)	*Lysiloma latisiliquum*	(6.31)		
Lonchocarpus xuul	(4.03)	*Pouteria campechiana*	(4.19)	*Ficus sp* (Linneo, 1753)	(4.16)				
				Lonchocarpus xuul	(4.13)				
Total	85.20		78.60		61.81		57.48		55.58

[a] Importance value of each species

frequency class 5 (2) and the 10-, 15- and 20-year-old vegetation groups.

The Shannon–Wiener index indicates statistically significant differences in species diversity between 5-year-old vegetation with a high cropping frequency (5 (2)) and the 10-, 15-, and 20-year-old secondary vegetation plots with a low cropping frequency. No significant differences were found between 5 (1) and all older secondary vegetation.

The evenness index was relatively similar over all secondary age–frequency classes, with the exception of 5 (2). This class exhibits a low evenness value as a result of low total species abundance, which is significantly different from others, as a result of low total species abundance.

Discussion

Interestingly, maize production, the mainstay of cultivation in the SY since ancient Maya times, is simultaneously declining in area and amount but increasing in temporal intensity throughout the region. The average area of maize cultivation per household dropped from 4.51 ha in 1997 to 3.28 ha in 2003, and in some communities, less than half of the previous maize farming households are now engaged in maize cultivation. This decline reflects the loss of guaranteed state price support for the crop in the current regional economy, and the production of maize foremost for direct consumption among households that are

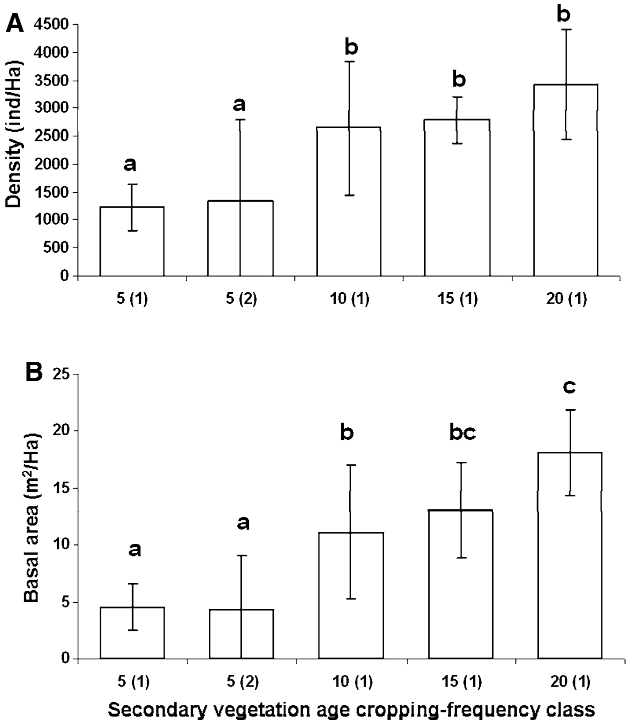

Fig. 1 Average density and basal area in the five secondary vegetation age-cropping frequency groups. *Different letters* indicate significant statistical differences between the groups result of one-way ANOVA ($P < 0.05$, $n = 23$, ±standard deviation)

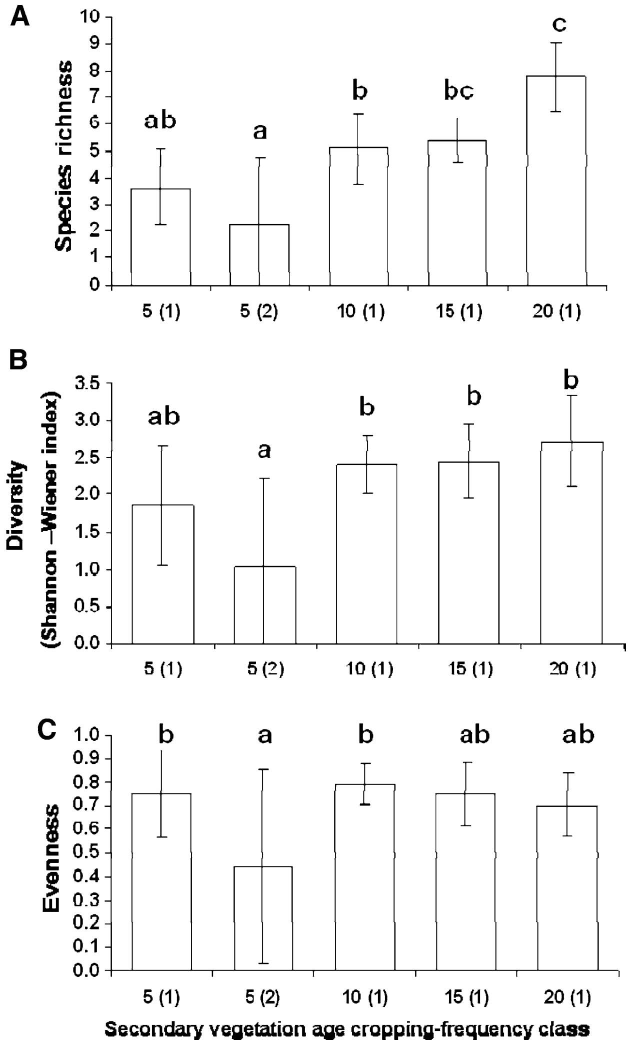

Fig. 2 Average species richness, tree diversity (Shannon–Wiener) and evenness index in the five secondary vegetation age-cropping frequency groups. *Different letters* indicate significant statistical differences between the groups result of one-way ANOVA ($P < 0.05$, $n = 23$, ±standard deviation)

otherwise diversifying their income strategies (Radel and Schmook 2008; Radel et al., this issue; Gurri, this issue).

Despite the de-emphasis of maize cultivation and the relative land abundance in the SY, households are intensifying their crop–fallow cycles for maize plots. Indeed, the higher end cropping frequencies in the SY are relatively intensive for shifting cultivation in general. The average crop–fallow cycle for the year of study (2003) for maize-only plots was 3.12 years of cultivation and 5.88 years of fallow. This cropping frequency does not follow from any apparent pressures on land or production; no statistical relationship was found between cropping frequencies for maize and population density, for example. Rather, the expressed rationales for focusing on secondary vegetation, increasingly younger secondary growth, include: the low amount (less than 6 ha) of older growth remaining for households in three communities (Table 1) and the need to conserve it for environmental benefits, such as its perceived role in supporting precipitation; the ease of clearing secondary growth (tree size) and planting because the soil is less compact, softer, and has fewer and smaller roots than soil in older growth; weed invasion of crop lands following secondary growth is not excessive; secondary vegetation dries and burns faster than older growth vegetation; the abundance of secondary growth ventilates cultivated plots better and heat damage to crops is less; plots taken from secondary vegetation are perceived to provide better yields, perhaps because of better soil moisture in secondary vegetation compared to older growth (Lawrence et al. 2007). Finally, as shown by Abizaid and Coomes (2004) for one of the communities in the study region, having a stock of early secondary vegetation can be interpreted as a claim to rights over lands.

Interestingly, no informant expressed the opinion that yields become inferior as the crop–fallow cycle shortened (and to our knowledge no field measures of yields have been undertaken in the region). These observations are consistent with the findings of Mertz (2002) and Mertz et al. (2008) that there is very little evidence of fallow length determining yields in shifting cultivation systems. In contrast, Lawrence et al. (2005, 2007), working in the SY but with different plots than used in this study, document that the number of cultivation cycles in the SY reduces not only above ground biomass but also available soil phosphorus, the last a critical nutrient for farm and forest. To date, the apparent discrepancy between the farmer's claims and the laboratory results has not been reconciled.

Regardless of the reasons, land in shifting maize cultivation in the SY incurs relatively high levels of temporal intensity. Opened land appears to be declining (see Rueda, this issue) but that which remains in under shifting cultivation maintains young secondary, little of which is allowed to reach older stages. Only 0.87% of lands in crop–fallow cycles reached the 20-year-old age class (Table 2) opposed to the 11.12% in secondary growth of five or less years. This intensification holds consequences for forest regeneration.

Early secondary vegetation has fewer tree species, families, and genera than older secondary vegetation. For the municipality of Escárcega, Campeche, just beyond the western boundaries of the SY and below 150 m elevation (see SYPR and SY area in Turner, this issue), researches report that the absolute number of species increases with the age of secondary vegetation (Centeno 1989; Chavelas-Pólito 1968; Manzanilla 1980). For these forests, only a few tree species contribute to more than 50% of the importance value in all secondary vegetation-cropping frequency groups. In my study, as much as 85% of the importance is made up by 8 species in group 5 (1) and as much as 78% made up by 8 species in group 5 (2). These values decrease across the older groups. These results hint of a long-term narrowing in species composition among the lands employed in shifting cultivation.

The dominance of *Lysiloma latisiliquum* (Fabaceae) in the early stages of secondary vegetation in shifting cultivation systems has been reported for northern Quintana Roo (Valdéz-Hernández et al. 2008). The Fabaceae is recognized as a pioneer family in secondary vegetation in the neotropics in general (Álvarez-Yépiz et al. 2008; Chavelas-Pólito and Contreras 1990; González-Iturbe et al. 2002; Hallé et al. 1978; Ochoa-Gaona et al. 2007; Whitmore 1975). Species common in mature vegetation were also recorded and included *Bursera simaruba* (in all five groups), *Manilkara zapota* (10, 15), *Dendropanax arboreus* (10, 20), and *Metopium brownii* (10, 15, 20). These six species re-sprout quickly, which allows for rapid establishment after the disturbances.

Other research in seasonally dry forests has shown that re-sprouting is the most effective mechanism of regeneration (Ewel 1980; Kennard 2002; McLaren and McDonald 2003; Murphy and Lugo 1986a; Vieira and Scariot 2006). Trees and shrubs and their subsequent regeneration do not, however, establish in an area free of propagules. Further, Valdéz-Hernández et al. (2008) observed that regeneration was much faster after burning than after bulldozer treatment because burning left vegetative structures—roots and rhizomes—intact. It is also noteworthy that during the early to late phases of secondary growth, mature forest species, such as *zapote*, a keystone species, typically do not fruit (Lawrence 2004; Weterings et al. 2008).

Significant structural differences in density and basal area between the two early age–frequency and the older groups were observable, whereas differences between the two 5-year age classes (5 (1) and 5 (2)) could not be distinguished. This observation suggests that cropping frequencies may not affect structural vegetation parameters. The sample size of 23 secondary vegetation plots is, however, small and the results warrant further examination.

Conclusion

Shifting cultivation in the SY within and around the CBR approaches the higher levels of temporal intensification for such low-input systems, reducing the number of species regenerating on crop–fallow parcels. This result may not constitute an immediate threat to overall tree biodiversity in the region, however, for two reasons: (a) species-wise, the CBR represents the regional ecocline reasonably well, and its presence appears to have reduced shifting cultivation within its borders (Vester et al. 2007); and (b) the number of patches of older growth currently spared from human disturbance from shifting maize cultivation, owing to the intensification process, suggests increased area of biotic diversity beyond the reserve as noted by Rueda (this issue) (see also Figueroa et al. 2009). Several caveats are warranted, however. Land dynamics in this "hollow frontier" (Busch and Geoghegan, this issue) have been volatile and could change, promoting and expansion of cultivation, including pasture, and thus the area in which forest regeneration would be challenged. Indeed, if current cropping practices hold into the future, the loss of available soil phosphorous documented with temporal intensification may ultimately reach a tipping point relative to yields (Lawrence et al. 2007). Consequently, farmers may switch cultivation to parcels of older secondary vegetation or even old-growth forest, reducing species diversity beyond the phosphorus-depleted abandoned plots. Indeed, this kind of response has been observed relative to land lost in the SY to invasion by bracken fern (Schneider and Geoghegan 2006).

These caveats are amplified by the distribution of land disturbances. Cultivation is concentrated, especially along the north–south and east–west highways that dissect the SY. In these areas, the proportion of the landscape covered by secondary growth is large (Rueda, this issue), as is the presence of pasture lands and chili cultivation (Busch and

Geoghegan, this issue). Together, these land-uses generate large and almost continuous patches of open land and early secondary vegetation that potentially serve as impediments to the connection and flow of biota across the ecocline of the SY. Over the long-term, the temporal intensification preference in current cropping practices is likely to create a less species-rich landscape barrier than has existed to date and one that will take much longer to re-establish to mature conditions if abandoned, for whatever reason.

As land change science researchers search for sustainable land architectures in tropical forest biomes (Turner et al. 2007; Turner 2009), especially those consistent with the goals of biosphere reserves, the implications of low-input but temporally intensive shifting cultivation warrant much further examination. This will prove to be the case in the SY, should economic dynamics sustain or increase current cultivation practices, especially given the regional ecological missions of the CBR and MBC, two entities established to facilitate the preservation of biodiversity.

Acknowledgments I thank B. L. Turner II, Deborah Lawrence, Hans Vester, Rebecca Dickson and Mirna Canul Montañez for their comments on previous drafts. Special thanks go to Dalia Hoil Villalobos who assisted me with species counts in secondary forest and to the kind farmers in the SY who put up with long hours of interviewing. I also thank two anonymous reviews who provide excellent direction in the development of this paper. Core funding for the Southern Yucatán Peninsular Region project from 1997 to 2009 was provided by NASA's LCLUC program (NAG 56046, 511134, 06GD98G) and NSF's BCS program (0410016). An additional sponsor of the research reported in this paper was the Mexican National Commission for the Knowledge and Use of Biodiversity, CONABIO (BJ002). The project is indebted to assistance provided by our host institution in Mexico, El Colegio de la Frontera Sur, especially Unidad Chetumal.

References

Abizaid C, Coomes OT (2004) Land use and forest fallowing dynamics in seasonally dry tropical forests of the southern Yucatán Peninsula, Mexico. Land Use Policy 21:71–84

Álvarez-Yépiz JC, Martinez-Yrizar A, Burquez A, Linquist C (2008) Variation in vegetation structure and soil properties related to land use history of old-growth and secondary tropical dry forest in northwestern Mexico. For Ecol Manag 256:355–366

Boserup E (1965) The conditions of agricultural growth: the economics of agrarian change under population pressure. Aldine-Atherton, Chicago

Boserup E (1988) Population growth as a stimulant to agricultural development. In: Steinmann G, Zimmermann KF, Heilig G (eds) Probleme und Chancen demographischer Entwicklungen in der dritten Welt. Springer, New York, pp 61–75

Brookfield HC (1984) Intensification revisited. Pac View 25:15–44

Brookfield HC (1993) Notes on the theory of land management. PLEC News Views 1:28–32

Brown S, Lugo AE (1990) Tropical secondary forests. J Trop Ecol 6:1–32

Brown D, Schreckenberg K (1998) Shifting cultivators as agents of deforestation: assessing the evidence. Nat Resour Perspect 29:1–14

Burgos A, Maass JM (2004) Vegetation change associated with land-use in tropical dry forest areas of Western México. Agric Ecosyst Environ 104:475–481

Centeno ELR (1989) Análisis estructural de cuatro etapas sucesionales de selva mediana subperennifolia en la región de Escárcega, Campeche. Tesis de Licenciatura, Universidad Autónoma de Chapingo, Estado de México, México

Chavelas-Pólito J (1968) Estudio florístico-sinecológico del campo experimental forestal "El Tormento", Escárcega, Campeche. In: Comisión de estudios sobre la ecología de Dioscóreas. Instituto nacional de Investigaciones Forestales, V Informe, México, D.F., pp 130–221

Chavelas-Pólito J, Contreras G (1990) Caracterización de la estructura de acahuales de diferentes edades. Taller internacional sobre investigación en silvicultura y manejo de selvas. SARH/INIFAP, México, D.F., México

Chidumayo EN (1987) A shifting cultivation land use system under population pressure in Zambia. Agrofor Syst 5:15–25

Daily GC, Ceballos G, Pacheco J, Suzan G, Sánchez-Azofeifa A (2003) Countryside biogeography of neotropical mammals: conservation opportunities in agricultural landscapes of Costa Rica. Conserv Biol 17:1814–1826

DeFries R, Hansen A, Turner BL II, Reid R, Liu J (2007) Land use change around protected areas: management to balance human needs and ecological function. Ecol Appl 17:1031–1038

Doolittle WE (1984) Agricultural change as an incremental process. Ann Ass Am Geogr 74:124–137

Eastmond A, Faust B (2006) Farmers, fires and forests: a green alternative to shifting cultivation for conservation of the Maya forest. Landsc Urban Plan 74:267–284

Ewel JJ (1977) Differences between wet and dry successional tropical ecosystems. Geo Eco Trop 1:103–117

Ewel JJ (1980) Tropical succession: manifold routes to maturity. Biotropica 12:2–7

Figueroa F, Sánchez-Cordero V (2008) Effectiveness of natural protected areas to prevent land use and land cover change in México. Biodivers Conserv 17:3223–3240

Figueroa F, Sánchez-Cordero V, Meave JA, Trejo I (2009) Socio-economic context of land use and land cover change in Mexican biosphere reserves. Environ Conserv 3:180–191

Finegan B (1996) Pattern and process in neotropical secondary rain forests: the first hundred years of succession. Trends Ecol Evol 11:119–124

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin F, Stuart C, Michael T, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. Science 309:570–574

Fujisaka S, Hurtado L, Uribe R (1996) A working classification of slash-and-burn agricultural systems. Agrofor Syst 34:151–169

Gehring C, Denich M, Vlek PLG (2005) Resilience of secondary forest regrowth after slash-and-burn agriculture in central Amazonia. J Trop Ecol 21:519–527

Gleave MB (1996) The length of the fallow period in tropical fallow farming systems: a discussion with evidence from Sierra Leone. Geogr J 162:14–24

González-Iturbe JA, Olmsted I, Tun Dzul F (2002) Tropical dry forest recovery after long term Henequen (sisal, *Agave fourcroydes* Lem.) plantation in northern Yucatan, Mexico. For Ecol Manag 167:67–82

Hallé F, Oldeman RA, Tomlinson PB (1978) Tropical trees and forests an architectural analysis. Springer, New York

Haug GH, Günther D, Peterson LC, Sigman DM, Hughen KA, Aeschlimann B (2003) Climate and the collapse of Maya civilization. Science 299:1731–1735

Ickowitz A (2006) Shifting cultivation and deforestation in tropical Africa: critical reflections. Dev Change 37:599–626

Illsley CE, Hernández-Xolocotzi E (1982) La vegetación en relación a la producción agrícola en el ejido de Yaxcaba, Yucatán. In: Hernández Xolocotzi E, Padilla I, Ortega R (eds) Seminario sobre producción agrícola en Yucatán. Gobierno del Estado de Yucatán, Mérida, México, pp 343–371

Joosten JHL (1962) Wirtschaftliche und agrarpolitische Aspekte tropischer Landbausysteme (*mimeo*). Institut für landwirtschaftliche Betriebslehre, Göttingen, Germany

Kennard DK (2002) Secondary forests succession in a tropical dry forest: patterns of development across a 50-year chronosequence in lowland Bolivia. J Trop Ecol 18:53–66

Klepeis P, Vance C, Keys E, Macario Mendoza P, Turner BL II (2004) Subsistence sustained: swidden or *milpa* cultivation. In: Turner BL II, Geoghegan J, Forster DR (eds) Integrated land-change science and tropical deforestation in the southern Yucatán: final frontiers. Oxford University Press, Oxford, pp 189–207

Lawrence D (2004) Erosion of tree diversity during 200 years of shifting cultivation in Bornean rain forest. Ecol Appl 14: 1855–1869

Lawrence D (2005) Biomass accumulation after 10–200 years of shifting cultivation in Bornean rain forest. Ecology 86:26–33

Lawrence D, Suma V, Mogea JP (2005) Change in species composition with repeated shifting cultivation: limited role of soil nutrients. Ecol Appl 15:1952

Lawrence D, D'Odorico P, Diekmann L, DeLonge M, Das R, Eaton J (2007) Ecological feedbacks following deforestation create the potential for a catastrophic ecosystem shift in tropical dry forest. Proc Natl Acad Sci 104:20696–20701

Lebrija-Trejos E, Bongers F, Perez-Garcia EA, Meave JA (2008) Successional change and resilience of very dry tropical deciduous forest following shifting agriculture. Biotropica 40: 422–431

Levy-Tacher S (1990) Sucesión secundaria en Yucatán: antecedentes para su manejo. Tesis de Maestría. Colegio de Postgraduados, Chapingo, Estado de México, México

Manzanilla H (1980) Los sitios permanentes de investigación silvícola del INIFAP. Un sistema integrado para iniciarse en el cultivo de los ecosistemas forestales. SARH-SDFAF-INIFAP, México, D.F., México

Marín-Spiotta E, Ostertag R, Silver WL (2007) Long-term patterns in tropical reforestation: plant community composition and above-ground biomass accumulation. Ecol Appl 17:828–839

McConnel W, Keys E (2005) Meta-analysis of agricultural change. In: Moran E, Ostrom E (eds) Seeing the forest and the trees. MIT Press, Cambridge, MA, pp 325–353

McLaren KP, McDonald MA (2003) Coppice regrowth in a disturbed tropical dry limestone forest in Jamaica. For Ecol Manag 180:99–111

MEA-Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: synthesis. Island Press, Washington, DC

Mertz O (2002) The relationship between fallow length and crop yields in shifting cultivation: a rethinking. Agrofor Syst 55:149–159

Mertz O, Wadley RL, Nielsen U, Bruun TB, Colfer CJP, De Neergaard A, Jepsen MR, Martinussen T, Zhao Q, Noweg GT, Magid J (2008) A fresh look at shifting cultivation: fallow length an uncertain indicator of productivity. Agric Syst 96:75–84

Mertz O, Leisz SJ, Heinimann A, Rerkasem K, Thiha, Dressler W, Pham VC, Vu KC, Schmidt-Vogt D, Colfer CJP, Epprecht M, Padoch C, Potter L (2009) Who counts? Demography of swidden cultivators in Southeast Asia. Hum Ecol. doi:10.1007/s1074450099249y

Miranda F, Hernández Xolocotzi E (1963) Los tipos de vegetación de México y su clasificación. Bol Soc Bot Mexico 28:29–179

Murphy PG, Lugo AE (1986a) Ecology of tropical dry forests. Annu Rev Ecol Syst 17:67–88

Murphy PG, Lugo AE (1986b) Structure and biomass of a subtropical dry forest in Puerto Rico. Biotropica 18:89–96

Murphy PG, Lugo AE (1995) Dry forests of Central America and the Caribbean. In: Bullock S, Mooney HA, Medina E (eds) Seasonally dry tropical forests. Cambridge University Press, Cambridge, pp 9–34

Netting RM (1993) Smallholders, householders: farm families and the ecology of intensive, sustainable agriculture. Stanford University Press, Stanford, CA

Ochoa-Gaona S, Hernández-Vázquez F, de Long BHJ, Gurri-García FD (2007) Pérdida de diversidad florística ante un gradiente de intensificación del sistema agrícola de roza-tumba y quema: un estudio de caso en la Selva Lacandona, Chiapas, México. Bol Soc Bot Mexico 81:65–80

Odum EP (1985) Ecología. Interamericana S.A de C.V, México, D.F., pp 158–178

Pascual U, Barbier EB (2006) Deprived land-use intensification in shifting cultivation: the population pressure hypothesis revisited. Agric Econ 34:155–165

Peña-Claros M (2003) Changes in forest structure and species composition during secondary forest succession in the Bolivian Amazon. Biotropica 4:450–461

Pennington TD, Sarukhán J (1998) Árboles tropicales de México: Manual para la identificación de las principales especies. Universidad Nacional Autónoma de México y Fondo de Cultura Económica, México, D.F., p 521

Pérez-Salicrup DR (2004) Forest types and their implications. In: Turner BL II, Geoghegan J, Forster DR (eds) Integrated land-change science and tropical deforestation in the southern Yucatán: final frontiers. Oxford University Press, Oxford, pp 63–80

Pinard MA, Putz FE, Rumiz D, Guzman R, Jardin A (1999) Ecological characterization of tree species for guiding forest management decisions in seasonally dry forests in Lomerio, Bolivia. For Ecol Manag 113:201–213

Radel C, Schmook B (2008) Male transnational migration and its linkages to land use change in a southern Campeche ejido. J Lat Am Geogr 7:59–84

Romero-Duque LP, Jaramillo VJ, Pérez-Jiménez A (2007) Structure and diversity of secondary tropical dry forests in Mexico, differing in their prior land-use history. For Ecol Manag 253:38–47

Roy Chowdhury R, Turner BL II (2006) Reconciling agency and structure in empirical analysis: smallholder land use in the southern Yucatán, Mexico. Ann Ass Am Geogr 96:302–322

Ruthenberg H (1980) Farming systems in the tropics. Claredon Press, Oxford

Saldarriaga JG, West DC, Tharp ML, Uhl C (1988) Long-term chronosequence of forest succession in the upper Rio Negro of Colombia and Venezuela. J Ecol 76:938–958

Sánchez PA (1976) Properties and management of soils in the tropics. Wiley, New York

Sarukhán J, Hernández Xolocotzi E (1970) Sinecología de las selvas de *Terminalia amazonia* en la vertiente del Golfo de México: análisis de la metodología de estudio. Bol Inst For Latinoamericano 34:3–20

Schneider L, Geoghegan J (2006) Land abandonment in an agricultural frontier after a plant invasion: the case of bracken fern in southern Yucatán, Mexico. Agric Res Econ Rev 35:1–11

Sheil D (2001) Conservation and biodiversity monitoring in the tropics: realities, priorities, and distractions. Conserv Biol 15:1179–1182

Shriar AJ (2000) Agricultural intensity and its measurement in frontier regions. Agrofor Syst 49:301–318

Sosa V, Flores S, Rico-Gray V, Lira R, Ortiz JJ (1985) Etnoflora yucatanense. Lista florística y sinonimia maya. Fascículo 1. Instituto Nacional de Investigaciones sobre Recursos Bióticos (INIREB), Xalapa, Veracruz, México

Téllez-Valdés O, Sousa-Sánchez M, Cabrera E (1982) Imágenes de la Flora Quintanarroense. CIQRO, Puerto Morelos, Quintana Roo, México

Turner BL II (2009) Sustainability and forest transitions in the southern Yucatán: the land architecture approach. Land Use Policy. doi:10.1016/j.landusepol.2009.03.006

Turner BL II, Brush SB (1987) Comparative farming systems. Guilford Press, New York

Turner BL II, Doolittle WE (1978) The concept and measure of agricultural intensity. Prof Geogr 30:297–301

Turner BL II, Hanham RD, Portararo AV (1977) Population pressure and agricultural intensity. Ann Ass Am Geogr 67:384–396

Turner BL II, Lambin EF, Reenberg A (2007) The emergence of land change science for global environmental change and sustainability. Proc Natl Acad Sci 104:20666–20671

Valdéz-Hernández M, Sánchez-Sánchez O, Islebe G (2008) Recovery and succession in a dry tropical forest of southeastern México (unpublished manuscript)

Vester HFM (1997) The trees and the forest. The role of tree architecture in canopy development; a case study in secondary forests (Araracuara, Colombia). Academisch Proefschrift, The Netherlands

Vester HFM, Lawrence D, Eastman JR, Turner BL II, Calmé S, Dickson R, Pozo C, Sangermano F (2007) Land change in the southern Yucatán and Calakmul biosphere reserve: implications for habitat and biodiversity. Ecol Appl 17:989–1003

Vieira DLM, Scariot A (2006) Principles of natural regeneration of tropical dry forest for restoration. Restor Ecol 14:11–20

Weterings MJA, Weterings-Schonck SM, Vester HFM, Calmé S (2008) Senescence of *Manilkara zapota* trees and implications for large frugivorous birds in the Southern Yucatan Peninsula, Mexico. For Ecol Manag 256:1604–1611

Whitmore TC (1975) Tropical rain forests of the Far East. Oxford Clarenton Press, London

Wilken GC (1987) Good farmers: traditional agricultural resource management in México and Central America. University of California Press, Berkeley

Wittemyer G, Elsen P, Bean WT, Burton ACO, Brashares JS (2008) Accelerated human population growth at protected area edges. Science 321:123–126