STRENGTHENING CONNECTIONS BETWEEN SCIENCE AND PUBLIC POLICY: FOREST CONVERSION IN THE TROPICS AND ASSOCIATED IMPACTS ON FOREST COVER AND HYDROLOGY

A Thesis

by

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ABSTRACT

Despite the prevailing assumption that hydrological flow variation is amplified and runoff increased with deforestation, evidence behind these claims is limited for very moist tropical regions. Data derived from field observations are needed to productively manage forested watersheds, optimize global climate models, and inform policymaking. First, I used a case study from mature forest and crop fields in Costa Rica to improve understanding of hydrological effects of forest conversion in tropical forests. Furthermore, I conducted a systematic review of the impact of public policies on forest cover in Mesoamerica.

Examining micrometeorological differences between mature forest and cropland, leaf wetness duration (LWD) was 5 times longer in the forest. Within crop species, papaya dried significantly slower than the shorter taro and sweet potato. Average daily evapotranspiration (ET_{crop}) as calculated by the FAO56 modified Penman-Monteith crop coefficient method was 2.75 mm for forest compared to crop values for papaya (1.83), taro (1.76), and sweet potato (1.43). These results suggest the possibility of higher runoff and alteration of rainfall recycling in the humid tropics following forest conversion to cropland. Canopy height and LWD seemed to be good indicators of differences in ET_{crop}.

In order to successfully protect forests, the public policy type most likely to result in positive effects was market-based conservation, as zero cases were linked to increased deforestation or decreased forest cover. 81% of the community based

management policy cases and 66% of the protected areas cases were positive. 83% of the agricultural policy cases resulted in more deforestation.

In order to increase effectiveness of forest conservation strategies, scientific reporting, such as this study, contributes knowledge to help inform policy. It can be inferred that longer LWD is associated with higher evapotranspiration of intercepted rainfall and lower runoff ratios in tropical forests compared to croplands. Therefore future policy directed at hydrological services should consider estimates of runoff from agricultural conversion in their decision-making process and target watersheds with high flood hazard potentials associated with large-scale deforestation.

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Contributors

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CHAPTER I

INTRODUCTION

Forest conservation is a high profile item on the global climate agenda. For example, REDD+ (Reducing Deforestation and Degradation in the tropics) is potentially a significant financial mechanism for altering decision-making incentives from deforestation and forest degradation to forest conservation and stewardship. A global consensus brokered by the UN REDD+ program offers incentives to developing countries to reduce emissions from forested lands and invest in sustainable forest management and development (Karsenty et al. 2008). Forest conservation is frequently cited as a mechanism for reducing carbon emissions, preserving biodiversity, and enhancing hydrological services, particularly in the humid tropics. While a cohesive literature exists substantiating the first two claims, the link between forests and water has still not been fully elucidated. In order to protect forests, we must understand their biophysical properties as well as the human processes underlying land use change. This highlights the importance of better understanding the impacts of deforestation on the water budget as well as improving knowledge of the effects of different public policies on forest cover between countries and within regions.

Water and Policy

When humans alter the vegetation in a given environment, we disturb much more than simply the aesthetics of the place; soil biogeochemistry is often perturbed, biodiversity can be harmed, and important hydrological processes may be impeded or shifted. Even in hydrological systems not traditionally experiencing water stress, such as very wet tropical regions, fluctuations in climate combined with land use decisions can alter the waterscape at a scale affecting humans. However, in part due to the current abundance of water in these areas, they tend to be less studied than arid ecosystems (Bruijnzeel and Sampurno 1990, Bruijnzeel 2004).

Many forest policies are specifically aimed at improving water resources; however, they may be based on assumptions that forests are simply “good” for water. For example, the US National Forest Management Act dating back to 1897 cites conservation and enhancement of timber and water resources as a part of its reason for creating the national forests. Specifically, it aims to secure favorable water flow conditions and prevention soil erosion and compaction (Wilkinson and Anderson 1985). Similarly, the Multiple Use-Sustained Yield Act of 1960 lists watershed uses among its list of benefits to people, once again placing emphasis on providing stable water flows (Wilkinson and Anderson 1985).

This type of water-related goal for forest policy has also been employed across Central America and the Caribbean. For example, Grenada’s Forest, Soil and Water Conservation Ordinance of 1984 aims to preserve tree cover to prevent erosion and protect water supplies. Guyana, Jamaica, Dominica, Belize, Antigua and Barbuda among others cite maintenance and conservation of water supply as part of their forest management plans. Many of the specific laws make mention of integrated watershed management to protect hydrological services (FAO 1998).

In order to incentivize forest cover protection, innovative policies have been implemented, many of which make similar connections between forests and water. These include the famous case of Costa Rica's national payment for ecosystem services (PES) program, which states water purification, flow regulation, erosion control, and temperature equilibration as co-benefits of forest conservation (FONAFIFO 2014). Many other similar programs use protection of hydrological services as part of their program goals of conserving mature rainforest, with over forty different programs in Latin America alone that span from Mexico to Brazil to Ecuador (Wendland et al. 2010, Lurie et al. 2013, Muñoz Escobar, Hollaender, and Pineda Weffer 2013, Martin-Ortega, Ojea, and Roux 2013, Ojea and Martin-Ortega 2015, Muñoz-Piña et al. 2008). Some programs are specific to water, like Mexico's Payment for Hydrological Environmental Services Program, while other proposals bundle watershed services with others such as carbon sequestration.

Assumptions prevail about the positive link between forests and hydrological services, particularly in the public domain. While forests are thought to be critical for both water quality and quantity, especially forested watersheds upstream of major agricultural regions, so-called "sponge theory" oversimplifies this into the assumption that forests absorb most precipitation and subsequently release it as regulated groundwater flow. This concept has been discussed and challenged starting in the 1980s (Hamilton 1985, Hamilton, King, and Center 1983) and has often been inappropriately used to justify soil and water conservation, forest management, logging policy and consequently funding for said programs (FAO 2005).

In the wet tropics, definitive knowledge about aggregate forest impacts on hydrology and watershed dynamics following deforestation remains limited (Bonan 2008, Chaves et al. 2008, Lavigne et al. 2004). However, the current understanding of linkages between tropical forest cover and water has been amplified with many long-term and rigorous paired watershed field experiments of both deforestation (Scanlon et al. 2007, Cramer and Hobbs 2002) and afforestation (McLean 2001, Silberstein et al. 2004, Sahin and Hall 1996). Paired catchment studies essentially calibrate runoff of two watersheds with similar characteristics before and after a change in land use (for example maintaining forest in one and converting the other to agricultural land) while avoiding to a large extent climate variability and inter-basin variability (Andréassian 2004).

The conversion of forest to cropland and ensuing changes in canopy interception of rainfall can alter the amount of water evaporating and running off from land surfaces (Khatun, Imbach, and Zamora 2013). Deforestation can result in decreases in evaporation and precipitation due to altered surface roughness and albedo (Galarraga et al. 2007), impact water table depth, and increase runoff; the opposite effects occur in the case of afforestation (Beck et al. 2013, Van Dijk and Keenan 2007). Asdak et al. (1998) observed decreased rainfall interception loss with reduced canopy cover in progressively more open forest areas, as well as a study in Venezuela which found sevenfold reduction in foliage interception between tropical montane forest and pastureland paired with higher surface runoff and transpiration (Ataroff and Rada 2000). They propose discontinuous canopy structure rather than deforestation as the cause of the reduced evaporation.

In many cases, there is a widespread perception that deforestation causes increased flow variation, resulting in more intense and frequent flooding and droughts (Bonell 2010). The spread of this belief has been remarked upon by many in the scientific literature (Hamilton 1985, Kaimowitz 2004), especially as rigorous experimental studies often have contradicting results (Bruijnzeel 2004, Van Dijk et al. 2009). It seems that a problem that has been encountered within the policy realm is that perception may be driving policy decisions as opposed to scientific consensus.

Indeed, stream flows in forests as compared to deforested land were more stable in temperate regions during drought, but this is not fully confirmed in the humid tropics (DeFries and Eshleman 2004, Brown et al. 2005). However, a modelling experiment in Costa Rica did examine sequentially more deforested scenarios, from pristine to extreme deforestation, and found that less forest cover was associated with augmented runoff peaks and low flows (Birkel, Soulsby, and Tetzlaff 2012). However, to fully comprehend the effects of deforestation on humid landscapes, more study is needed. Without further validation, the hydrological knowledge behind the common presumptions underlying many public policy justifications in tropical regions may be incomplete.

To better design forest-based water policy based on current and region-specific hydrological knowledge, it is imperative we understand if changes in forest cover alter watershed services. To answer this question in a representative scenario, I did a case study in a premontane tropical forest in Costa Rica in which I aimed to evaluate the degree of hydrological alteration by conversion from mature forest to monoculture row crops in high rainfall environments. First, I compared LWD between vegetation types, then used this parameter as a proxy vegetation factor to estimate ET_{crop} from intercepted precipitation. This helps determine to what degree taller vegetation with more complex stand structure, like forests, intercepts more moisture and stays wetter for longer than short statured crops, releasing it to the atmosphere rather than it running off and increasing stream flow.

Given tropical forest conservation as a policy objective, it follows that an important challenge is to determine how public policies affect forest cover across specific sub-regions. To answer this question, I did a systematic literature review examining the forest cover changes resulting from public policies in Mesoamerica. Our goal was to determine whether some public policies consistently are more likely to be related to curbing deforestation and whether such trends are driven by discrete factors. Furthermore, we wanted to ascertain if the study of this research question is uniform or whether trends exist in the metadata.

CHAPTER II

HYDROLOGICAL EFFECTS OF FOREST CONVERSION TO CROPLAND

In tropical rainforests, large scale deforestation is considered one of the biggest threats to the environment. This threat is perceived as being attributable to a loss of biodiversity, carbon storage, and helpful hydrological services, such as erosion control, streamflow regulation, and water quality. However, the dynamics of tropical forest conversion to agricultural uses and the subsequent shifts in evapotranspiration (ET) and water recycling are not well understood. We examined potential changes in water storage in the vegetation within mature premontane forest in Costa Rica and adjacent crop fields of three varieties with distinct crown architectures, specifically focusing on LWD as a proxy for canopy storage and evaporation of intercepted rainfall. In addition, we used the FAO56 Penman-Monteith equation to estimate potential evapotranspiration (ET_{crop}) under different canopy types. Forest leaves stayed wet significantly longer than the crop fields (487 ± 41 minutes) as compared to (94 ± 37 minutes). Within crop species, papaya dried significantly slower than taro and sweet potato (137 ± 51 in contrast to 73 ± 23 minutes). Average ET_{crop} was found to be 2.75 ± 1.30 mm/day for forest compared to values for papaya (1.83 ± 0.86 mm/day), taro (1.76 ± 0.83 mm/day), and sweet potato (1.43 ± 0.67 mm/day), which we associated with differences in crop heights. Within the crop treatments, ET_{crop} of sweet potato was significantly less than the other two ($p < 0.01$ for all results). Crop heights were well correlated with dry-down rates ($r^2 = 0.98$). These results suggest the possibility of higher runoff and alteration of rainfall recycling in the humid tropics following tropical forest conversion to cropland.

Introduction

The relationship between forest and hydrological services, related to both quality and quantity, is complex. A growing scientific consensus considers that stream flows in temperate forests tend to have smaller peaks during flooding and sustain higher base flows during drought as compared to non-forested streams, but it is not clear if the same dynamics apply in the humid tropics (Brown et al. 2005). Furthermore, potential differences in stream flows may be associated with a variety of drivers, including higher consumption of water by vegetation in the form of transpiration, or greater canopy interception of rainfall. Either of these can impact the timing and magnitude of peak flows. Rainfall interception is of even greater importance in the humid tropics, as these regions experience frequent wet-dry cycles, considerable canopy interception, and high evaporation of intercepted precipitation, anywhere from 10-30% of gross rainfall (Calder, Wright, and Murdiyarso 1986, Bruijnzeel and Scatena 2011). This non-uniform distribution of hydrological evidence has a potential to bias our scientific understanding of forest impacts. It is reasonable to assume that fewer studies in the tropics may be due to remote access, or perhaps because hydrology research is more pressing in water-limited regions. Nevertheless, it is essential that natural resource managers make decisions based on sound science that is appropriate for their local conditions.

It is quite common for policies in Mesoamerica to cite hydrological benefits among the ecosystem services they attempt to conserve (Schomers and Matzdorf 2013).

For example, in Costa Rica and Mexico there are provisions for PES reliant on the apparent hydrological benefits provided by forests (FONAFIFO 2014, Muñoz-Piña et al. 2008). In particular, consistent quantity, or flow regulation, and water quality enhancements are mentioned (Martin-Ortega, Ojea, and Roux 2013). In many cases in Central America and Mexico, benefits identified by users such as reduced flood risk, constant drinking water supply, dry season availability for agriculture, and maintenance of ecological flows all point to the importance of consistent base flows (Porras, Grieg-Gran, and Neves 2008).

As a major hydrological service, runoff regulation is often of particular concern for small landowners. The presumption is that forested land improves this hydrological service. If throughfall differs significantly with forest cover changes, this has the potential to alter runoff patterns (Muñoz-Villers and McDonnell 2013). If not, the hydrological basis of conventional assumptions underlying many forest conservation policies in tropical regions may be deeply flawed.

Research looking at hydrological shifts accompanying vegetation changes in humid areas is directly applicable to similar regions. In fact, many reviews of such cases (see Bruijnzeel and Proctor 1995, Bruijnzeel 2004, Bowling, Storck, and Lettenmaier 2000, Brooks, Ffolliott, and Magner 2012, Calder 2001, Eisenbies et al. 2007, FAO 2005) broadly generalize the mechanisms by which forests may reduce chances of floods: through increased interception, evaporation, and reduced overland flow of water (see Appendix C for further information).

Rainfall interception has been widely studied in humid tropical systems (see Safeeq and Fares 2014, Chu et al. 2014, Giambelluca and Gerold 2011, Bruijnzeel and Scatena 2011, Holwerda et al. 2011, Takahashi et al. 2011). In most cases, deforestation scenarios have been associated with reduced interception, increased surface runoff (Maris 2015, Panday et al. 2015), and exacerbated streamflow peaks and low flows, as seen in Bruijnzeel and Scatena (2011), Ty, Sunada, and Ichikawa (2011), Laurance (2007), and Brookhuis and Hein (2016).

A study in Venezuela reported a sevenfold reduction in foliage interception between tropical montane forest and pastureland paired with higher surface runoff (Ataroff and Rada 2000). Asdak et al. (1998) found a similar decrease with reduced canopy cover in progressively more open forest areas: closed canopy, partial canopy and canopy gap respectively. They propose discontinuous canopy structure, rather than deforestation, as the cause of the reduced evaporation. Similarly, a modelling experiment in Costa Rica examined sequentially more deforested scenarios, from pristine to extreme deforestation, and found that although water yield was not significantly altered, forest cover was inversely related to runoff peaks and low flows (Birkel, Soulsby, and Tetzlaff 2012).

Most global climate models estimate ET based on calibrations made in more water-limited regions and use soil moisture availability as a primary driver. Yet, in tropical montane forests, it has been postulated that net radiation (R_{net}) rather than water availability drives ET (Fisher et al. 2009, Loescher et al. 2005). However, this phenomenon is not fully understood and supportive data for this claim are still limited.

For example, a model relating ET to precipitation based on over 250 cases included no data from catchments with annual rainfall of over 3500 mm (Zhang, Dawes, and Walker 2001).

In order to understand streamflow dynamics, it is useful to study interception and evaporation, as they are often linked (Bruijnzeel and Scatena 2011). However canopy interception differs by orders of magnitude over very short distances in heterogeneous natural forests, making it difficult to capture spatial variation adequately to produce reliable estimates. It is possible that other measures such as LWD may correlate well with canopy interception. LWD was determined mainly by post-rainfall evaporation rates (Kume et al. 2006), indicating it may also react to vegetative changes in a similar way to interception or evaporation rates. In our case, we utilized LWD as an indicator of canopy interception.

We use a case study in a Costa Rican premontane tropical forest to evaluate hydrological changes in a high precipitation environment by conversion from mature forest to monoculture row crops. First, we compare LWD as a proxy for evaporation from intercepted precipitation. Second, we estimate differences in evapotranspiration using micrometeorological parameters known to differ by canopy stature. This helps us determine to what degree taller, more complex vegetation intercepts more moisture and stays wet longer than short statured crops, releasing water to the atmosphere rather than it running off and increasing stream flow. We used LWD and estimated potential ET (ET_{crop}) to test their efficacy as useful proxies for estimating the evaporative portion of the water budget. This was then compared between forests and various crops commonly grown in this region.

Materials and Methods

Site Description

This study was located near San Isidro de Peñas Blancas, San Ramón canton, Alajuela province, Costa Rica, on land adjacent to the Children's Eternal Rainforest and the Texas A&M University Soltis Center for Research & Education (10°22'59.1"N, 84°37'06.4"W). All sites were located in the middle Chachagua watershed within 1.7 km from the center (see Figure 2). The elevation ranges from 400-500 m above sea-level, composed primarily of either mature premontane forest straddling the climate gradient between cloud forest and rainforest (Holdridge 1966) or converted agricultural land. Average annual temperature is 24ºC, while precipitation in this area averages 4200 mm per year, with mean monthly rainfall of 430 mm (130 mm in the dry season). This qualifies the site as moist tropical forest (D'Odorico et al. 2010).

The study compared microclimate within and under mature premontane transitional rainforest canopy to microclimate within the canopy boundary layer of three crop sites representative of even-aged monoculture plots papaya (*Carica papaya*), taro (*Colocasia esculenta*), and sweet potato (*Ipomoea batatas*) fields (see Figure 1). We further stratified the forest into two categories: closed canopy (mature forest); open canopy (downburst/forest gap). Measurements were collected over two months in June to August 2011 and during June to July 2014. . These vegetation types were chosen due to their economic value to Costa Rica and proximity to the forest sites (see Figure 2).

Within crops, the average canopy heights were 1.8, 1.3, and 0.7 m, respectively for papaya, taro, and sweet potato.

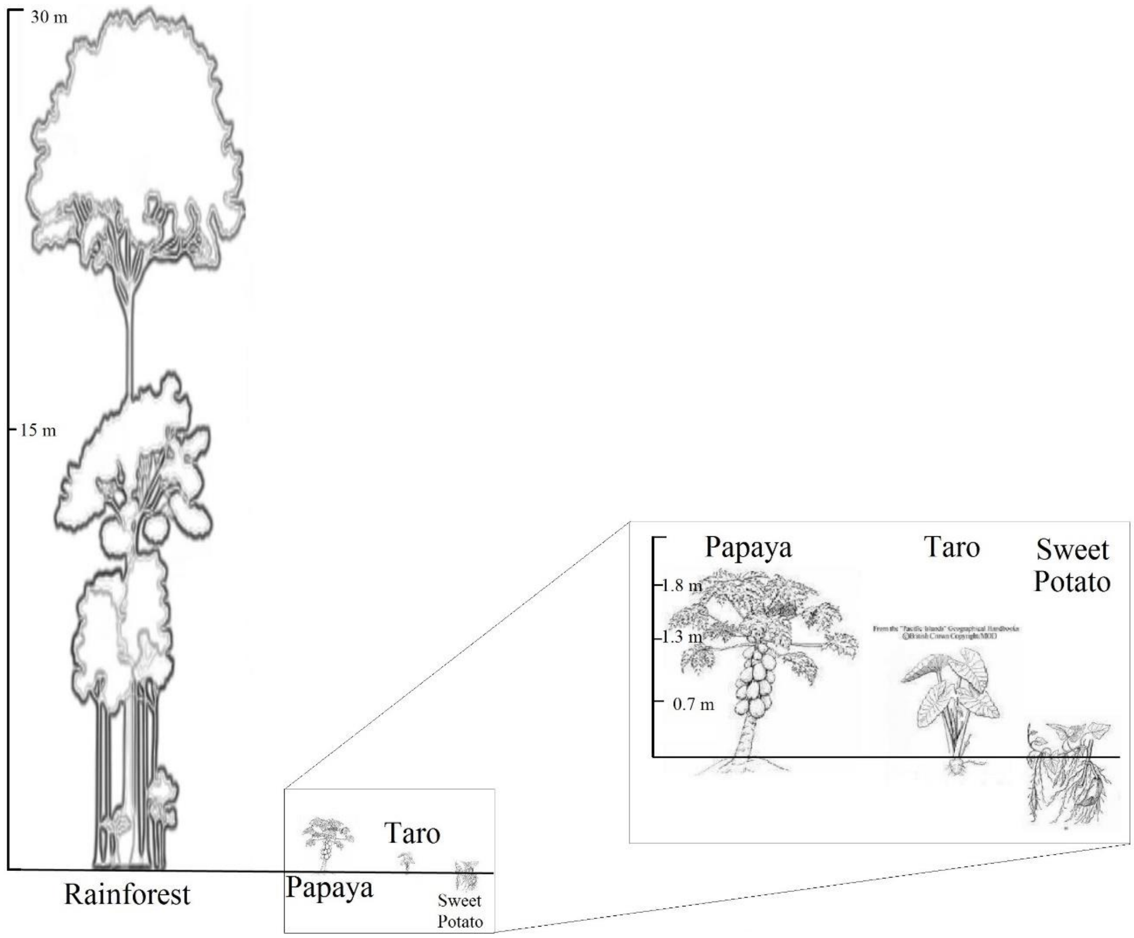

Figure 1. Heights and structure of each canopy condition: mature forest, papaya, taro, and sweet potato.

The forest vegetation is a mix of primary and secondary tropical premontane forest, predominantly composed of trees in the Sapotaceae (hibiscus), Moraceae (fig), and Malvaceae (milkwood) families (Miller et al. 2013). The closed canopy site was approximately 30 m in height and accessed by a 40 m tall micrometeorological tower.

Figure 2. Location of field plots. Stars in upper right quadrant indicate from L-R sweet potato, taro, and papaya; the star on the left indicates the approximate site of meteorological tower and forested plots.

Microclimatology Measurements

Continuous measurements of air temperature (°C), relative humidity (% humidity), and leaf wetness (%) were averaged every ten minutes. Sensors were mounted on an Onset Computer Corporation HOBO U30 datalogger and Remote Monitoring System (Bourne, MA, USA) placed in the center of the plots. An air temperature and humidity (sensor (HOBO S-THB-M00x) was mounted at approximately canopy height for the three crops. A S-LWA-M003 capacitive grid leaf wetness sensor (Onset Computer Corporation, Bourne, MA, USA) was mounted parallel to the ground at 1.62 m (papaya), 1.41 m (taro), and 0.95 m (sweet potato). To record total precipitation (mm) every 10 minutes, a rainfall tipping-bucket rain gauge (HOBO S-

RGA(B)-M002, Bourne, MA, USA) was installed near the top of each station ~1.9 m above the ground.

Leaf Wetness Duration

Leaf wetness in the covered forest condition was measured using a LWS-L dielectric LWD sensor (Campbell Scientific, Inc., Logan, UT, USA), which is based on the same dielectric principles as the Onset LWA sensors. Rain (or more rarely, condensed fog) was collected on the leaf wetness sensor and a current proportional to the water amount was detected by the data logger. The sensors were manually calibrated at saturation and fully dry end points, and the dryness threshold was determined to be 15%. The forest LWD measurements were taken at five heights on the walk-up tower, at 5, 12, 24, 34, and 40 m. For the LWS-L, the wet threshold was set at 400 and dry threshold at 125 (dimensionless units) according to the most consistent fit for the data based on methodology in Aparecido et al. (In Review).

Evapotranspiration and Transpiration Estimations

We estimated reference ET over a 1-year period using micrometeorological variables collected at the meterology tower at the Soltis Center, in an open area which approximated conditions for both forest and crop boundary layers. We used the FAO56 simplified model based on the Penman-Monteith equation (Allen et al. 1998). Yoder, Odhiambo, and Wright (2005) found that the Penman-Monteith method shows least percent mean error in estimating daily reference ET in a humid tropical climate.

FAO56 uses the following variables: ET_0 = reference evapotranspiration (mm/day); Δ = slope of the saturation vapor pressure curve (kPa/◦C); R_n = net radiation

(MJ/m^2 day); G = soil heat flux (MJ/m^2 day); γ = psychometric constant (kPa/ºC); T = mean air temperature (ºC); U_2 = average 24-h wind speed at 2 m height (m/s); and VPD = vapor pressure deficit (kPa), based on Allen et al. (1998).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T + 273}\right)U_2(e_a - e_d)}{\Delta + \gamma(1 + 0.34U_2)}$$

A crop coefficient (K_c) was applied for each vegetation type to simulate the different conditions of the five treatments and estimate ET_{crop} for each as K_c * ET_0 (Pereira et al. 2015). The most appropriate crop coefficients were chosen based on the literature (Allen et al. 2006). Sweet potato had a previously approximated crop coefficient of 0.65 in the FAO manual. However, the other crops and forest condition did not have established coefficients. Thus, the FAO coefficients from structurally similar crops were used to approximate the rest of the conditions; pumpkin/winter squash was used for taro (0.8), an average of tropical fruits and tropical trees (0.83) for papaya, and a value based on that of rubber trees/conifers was estimated for covered forest (1.25), see Table 12 in Chapter 6 of Allen et al. (1998).

Estimates of ET_{crop} were compared to available estimates of transpiration collected at our study site that were previously published in Aparecido et al. (In Review). Briefly, in their study, stand-level transpiration at the premontane forest site was estimated by sap flow measurements using heat dissipation probes based on Granier (1987). Transpiration (T, mm/day) was estimated using daily total sap flux density (J_s, kg/m^2 h) for the sampled trees (n = 26) multiplied by the total sapwood area per unit ground area in the 2200 m^2 plot (Aparecido et al. In Review, Moore et al. 2004). This enabled us to compare ET_{crop} and T in different crop and forest conditions, and by extension the T:ET ratio.

Data Analyses

Micrometeorological parameters that drive LWD and dry-down rate (temperature and relative humidity) were compared between the three different low-canopy crop treatments using data from the same time period. Least squared regressions were analyzed using the software Sigmaplot, as were all the following described analyses.

We also compared rate of leaf drying between crop sites and forested conditions. To meet the criteria for a dry-down event, the LWD sensor had to register 100% saturated and decline to the threshold dry level of 15% without an increase of >2% wetness over ten minutes. This stipulation ensured that an errant water droplet did not discount a dry-down event but eliminated breaks in precipitation during long storm events. These inclusion criteria were applied across sites and years, and as such, a total of 9 rain events that were representative of each condition were treated as replicates in the analysis. The data were rescaled with the threshold dry level documented as 0% wet.

For each 10-minute time point throughout the dry-down event, the difference in leaf wetness between sites was compared across all replicate events using a paired t-test (α-value of $p < 0.01$). Dry-down curves were best fit using logarithmic trend lines. We compared mean least squared differences in dry-down slopes to canopy height using a polynomial linear regression. We first increased all the data by two orders of magnitude and converted the dry-down rates to positive values. We were then able to logarithmically transform the values in order to reduce variance and keep the resultant data within the same order of magnitude.

To compare drying times between vegetation types, an analysis of variance (ANOVA) was applied for all paired treatment combinations. Afterwards we applied a Tukey's post-hoc test to separate the conditions into like groups by comparing their means.

Results

Comparison of Relative Humidity Between Crop Types

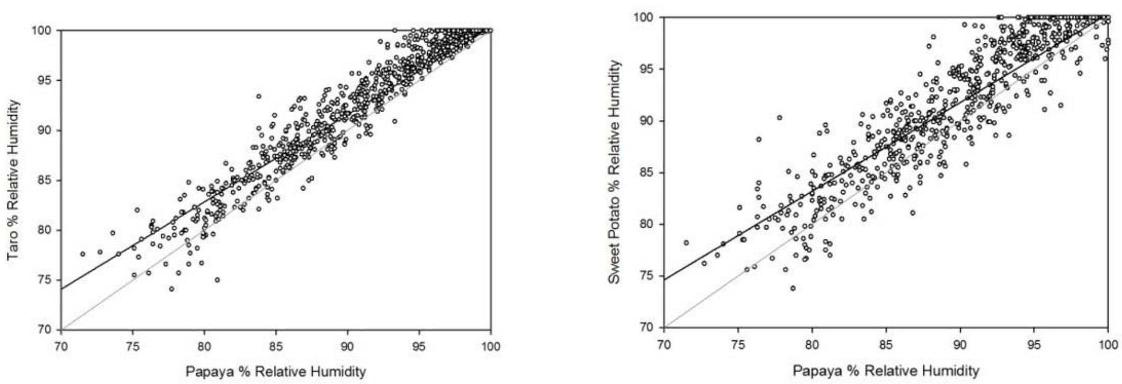

Figure 3. Above-canopy relative humidity (%) for taro (first panel) and sweet potato (second panel) as compared to the control plant papaya. Least squared regression lines are black (with goodness of fit of $r^2 = 0.98$ and 0.96 for taro and sweet potato). One-to-one lines are grey.

The air directly above papaya was consistently less humid than the other two crops throughout the three week period (see Figure 3); interestingly, many points were observed when taro and sweet potato were 100% humid while the air was not fully saturated in the papaya field: 11% and 15% of the time, respectively.

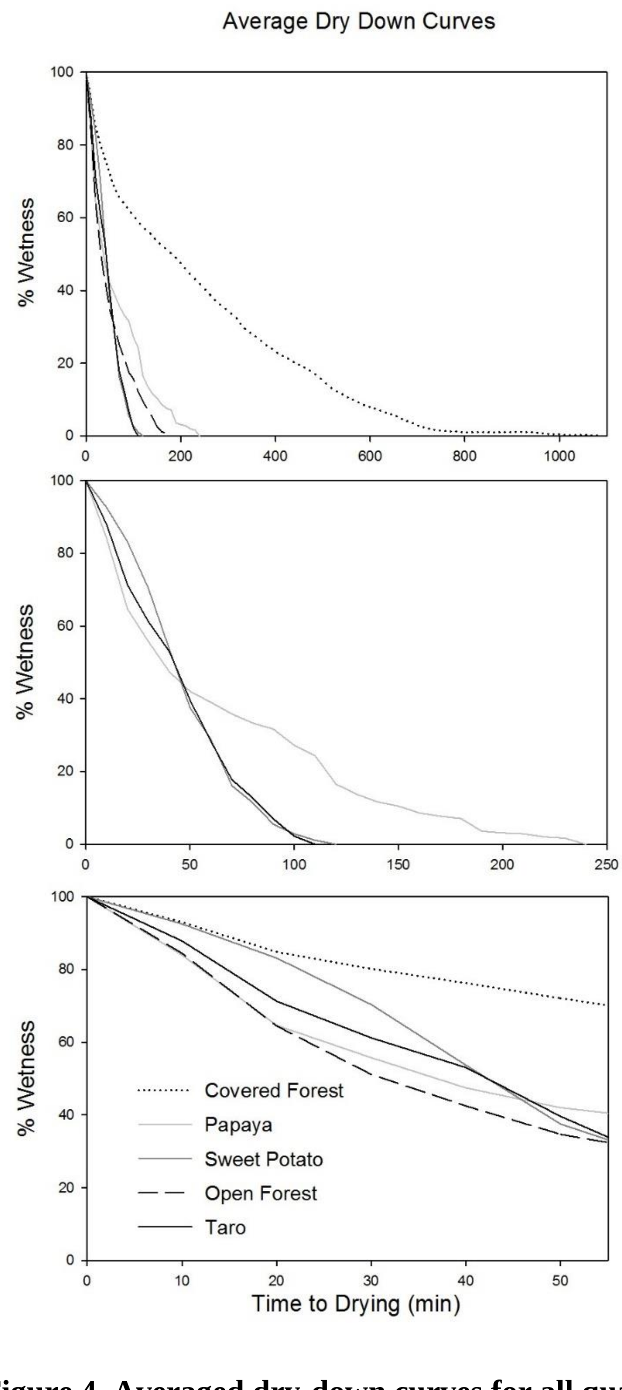

Figure 4. Averaged dry-down curves for all qualifying rain events in different vegetation types (first pane). Dry-down curves for the first 50 minutes after saturation (second pane). Dry-down curves for papaya, taro, and sweet potato from 0 to 250 minutes (third pane). All N = 9 coincident events.

After rain events, dry down curves followed a logarithmic decay trend (see Figure 4). Over the period from saturation to fully dry, all nine rain events followed a similar drying trend ($r^2 = 0.97, 0.99, 0.99, 0.99, 0.93$ for closed forest, open forest, papaya, taro, and sweet potato).

The closed canopy forest stayed on average wetter longer than any other vegetation type (see Figure 4, $p < 0.05$). Closed forest conditions dried at a relatively consistent rate after the initial 100 or more minutes, when the rate became less steep. When examining the initial drying period of one hour, a linear fit was most appropriate. Closed forest had a much less negative slope than all other conditions, -0.52% wetness lost per minute compared to -1.22 ± 0.07% per minute. Finally, forests took ~250 minutes longer to reach the level of dryness observed in crops after only one hour (see Figure 4).

Papaya retained wetness longer at a lower level after the initial period of similar drying instead of continuing to dry at a uniform rate. When comparing the three crops to each other on an individual scale, there is an apparent inflection point, before which the non-transformed slopes of the three crops were -12.16, -11.23, and -9.56, all very steep and similar ($r^2 = 0.93, 0.94, 0.87$, respectively for papaya, taro, and sweet potato). However, at 50 minutes papaya begins to have a slope of -1.72, less than 1/7 of the rate of change of that during the first hour, and LWD extends much longer than for the shorter canopy crops. Little difference was seen between taro and sweet potato, which is surprising considering sweet potato is a ground-cover crop and taro had a more distinctive canopy up to 1.3 m in height ($p < 0.05$, see Figure 4).

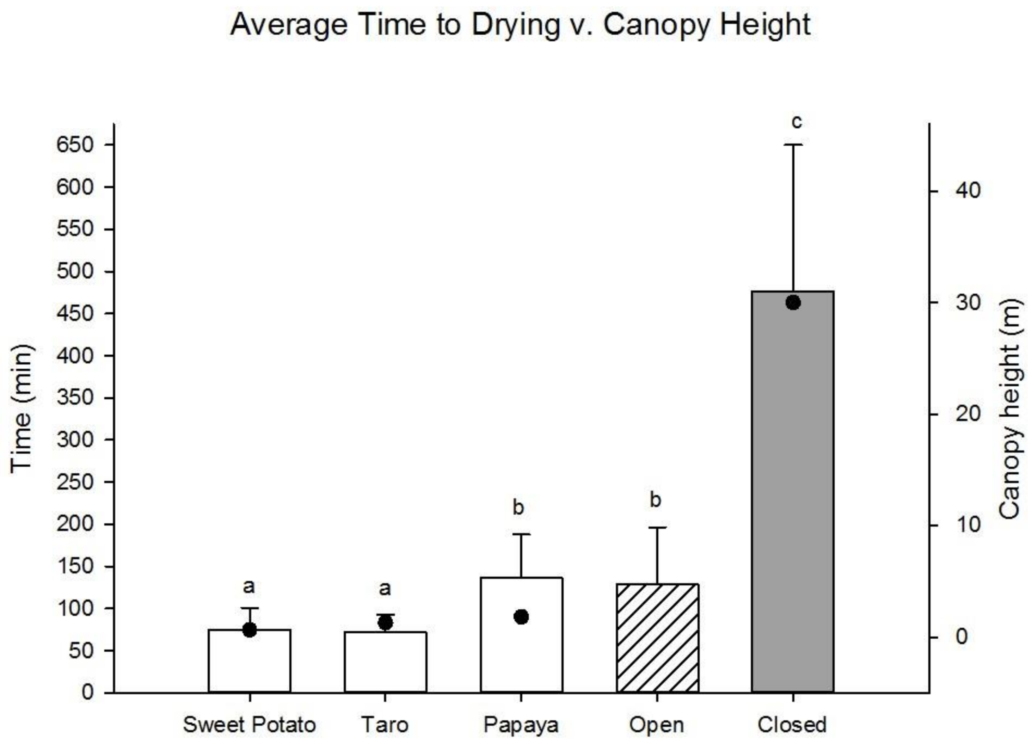

Figure 5. Mean LWD from saturated to 0% wetness with standard deviation for all vegetation types in three significantly different groups (left axis, bar graph) overlaid with canopy height for each type (right axis, scatter plot). (ANOVA Tukeys $p < 0.05$). N = 9.

The mean LWD in closed mature forest (476 ± 41 minutes) was almost five times greater than crops, which averaged 94 ± 37 minutes and more than 3.5 times the duration of open forest (129 ± 68 minutes, see Figure 5). When comparing the average LWD in minutes and overlaying this with canopy height, papaya behaved more similarly to open forest than to the lower crops despite being similar in height to the crops.

Papaya dried almost twice as slowly as the taro and sweet potato, 137 ± 51 in comparison with 73 ± 23 minutes (all with $p < 0.01$). LWD of sweet potato, taro, and papaya was 15, 20, and 33% that of the closed forest. These values were different than the ratio of FAO56 crop coefficients (52, 64, and 67% respectively). It is important to overlay crop height with LWD because we are interested in these parameters as a representative proxy for different types of vegetation.

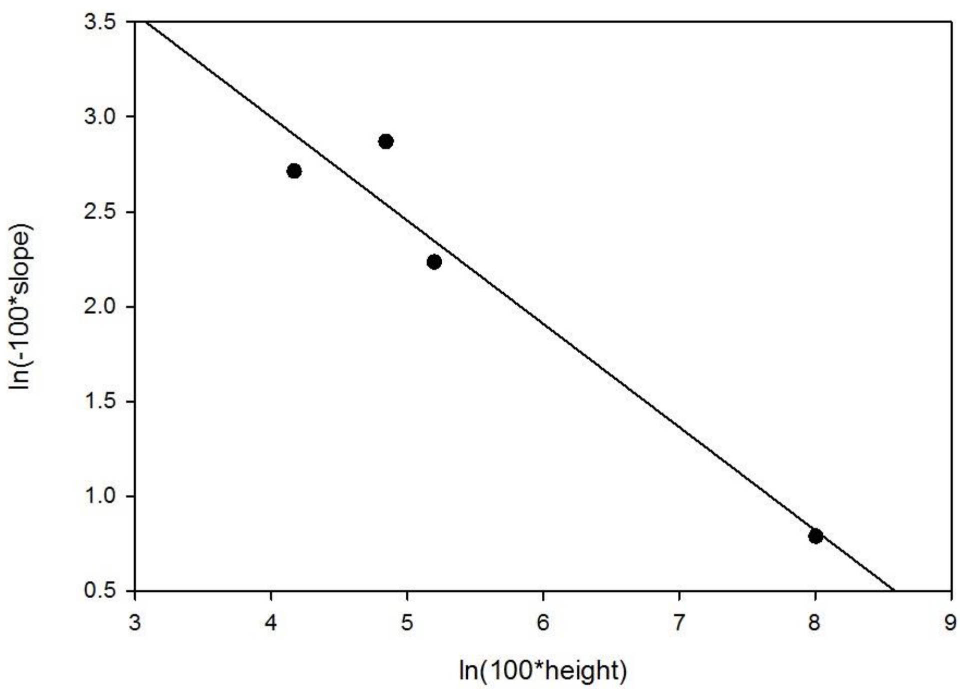

Figure 6. Comparison of log transformed canopy height and dry-down curve slope multiplied by a factor of |100| (r^2 = 0.94).

As height increased, the slope of the dry-down curve flattened, as is expected if the higher canopy and inter-canopy space retain moisture longer after a rain event. We found strong evidence that height was a major factor in determining LWD (r^2 = 0.94, see Figure 6).

Estimating ET_{crop}

ET_{crop} also differed between sites (see Figure 7), but to a lesser degree than differences in LWD. Average estimates of ET_{crop} over the one-year period for the crop fields were 668 (papaya), 642 (taro), and 522 mm (sweet potato). The closed-canopy mature forest estimate was 1004 mm (we did not attempt to estimate the open-canopy forest). Proportionally, ET_{crop} of sweet potato, taro, and papaya was 52, 64, and 67% that of the closed forest. Only papaya and taro were predicted to have similar ET_{crop} (see Figure 7), given their similar crop coefficients of 0.80 and 0.83. Total ET_{crop} was significantly higher in closed forests than monoculture crop fields, ($p < 0.01$).

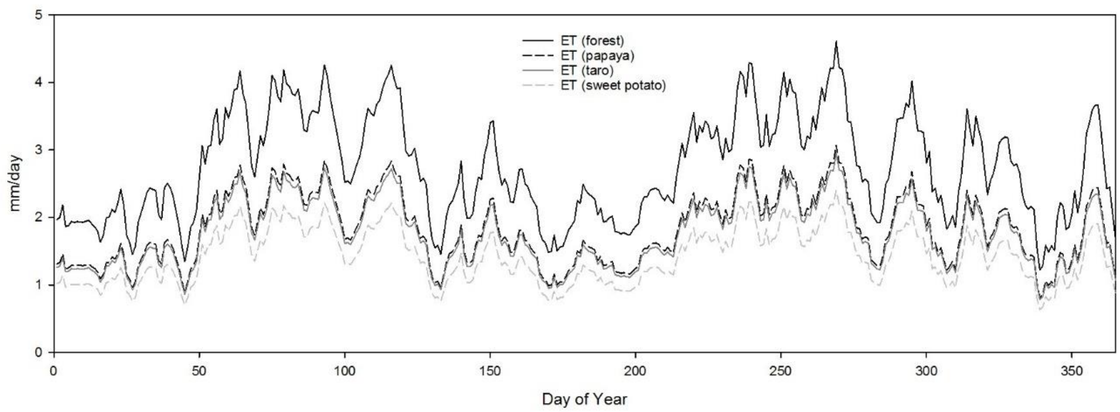

Figure 7. Summed daily seven day running mean ET_{crop} values for the closed forest and three crop vegetation types from August 2014 - July 2015.

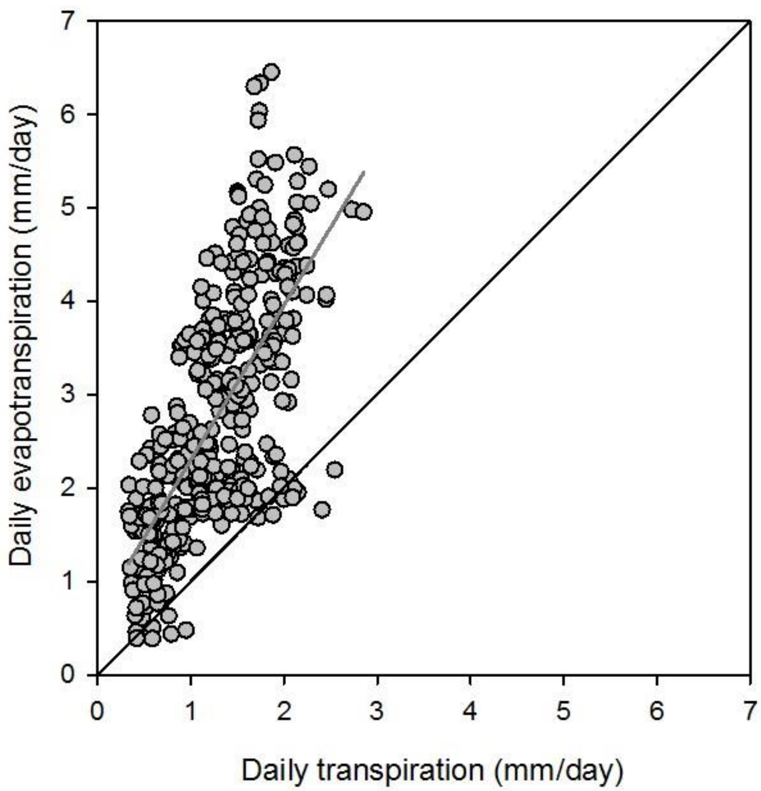

Figure 8. Total daily forest ET_{crop} as a function of transpiration had a coefficient of variation of 0.47 (from Aparecido et al. In Review).

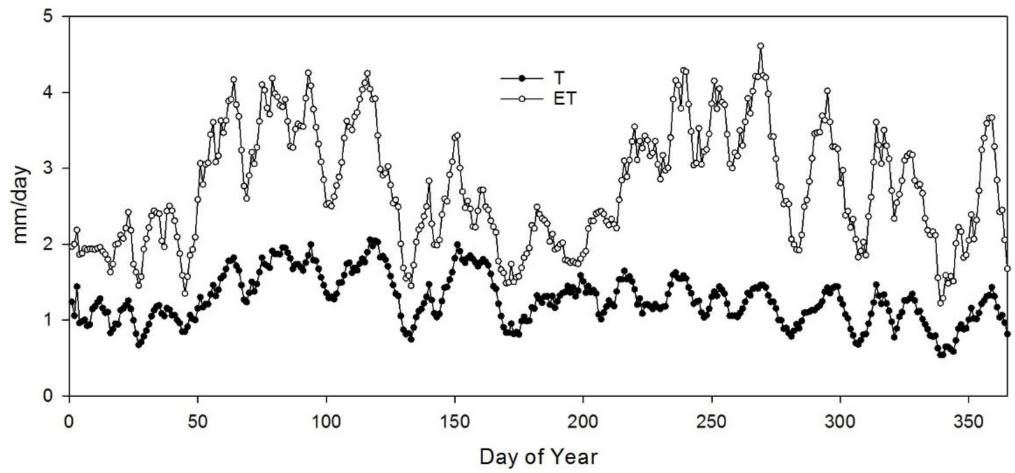

Figure 9. Summed daily seven day running mean ET_{crop} values for the closed forest compared to transpiration (Aparecido et al. In Review).

ET_{crop} averaged 2.1 times transpiration for covered forest conditions (see Figure 8), however the difference approached zero, especially on such days that both ET and T were low (see Figure 9, dry days). The greatest difference between ET_{crop} and T was seen during the rainy month of April. There were larger differences between ET_{crop} and T during the second half of 2014 than during the first half of 2015 using a Kruskal-Wallis ANOVA ($p < 0.01$).

Discussion

In very wet tropical systems, the use of LWD to distinguish the impact of deforestation on available water in the forms of canopy water storage capacity, intercepted rainfall, and leaf evaporation appears to have merit. LWD indicated overall hydrological differences between crops and forest, which translated into a five-fold longer LWD in forest than crop fields. This considerable difference in LWD is noteworthy, particularly since E is a large proportion of ET_{crop} in this forest (44-49%)

and important to the water budget in this system. This is consistent with previous findings, demonstrating that LWD varies depending on position in canopy and species tested (Sentelhas et al. 2005). Although we noted significant differences in LWD between short and tall statured crops, we were unable to discern difference between small crops using our measures.

Our results also demonstrate that both LWD and ET_{crop} contribute useful proxy information to the larger question about the impact of land use on hydrology. Premontane tropical forests undergo frequent wet-dry cycles, thus the fraction of the water budget affected by interception is relatively high compared to temperate regions. Increased LWD is indicative of higher surface area of leaves intercepting precipitation, which translates to less water reaching the ground surface and more potential for water storage on the canopy. LWD may therefore provide us with a simple way to extrapolate the effect of deforestation on streamflow. Our ET_{crop} model, similar to LWD, demonstrated a similar difference between vegetation types. Yet as ET_{crop} incorporates more than simply interceptive losses, it is a more “buffered” measurement than LWD, causing the differences between vegetation types to converge.

Species-specific crop coefficients are based in part on canopy height, which we showed is very closely tied to LWD. This substantiates the use of height in calculating crop coefficients for each species. Keeping in mind the subjective nature of crop coefficients, all crops showed a 33-48% reduction from forest ET_{crop} representing water not transpired or intercepted by the canopy. In a region with 4200 mm annual precipitation, this translates to an estimated decrease in interception loss of 334-481 mm per year or about 10% of annual precipitation. Bruijnzeel and Scatena (2011) indicated wet canopy evaporation ranged between 300-900 mm in lower montane cloud forests, so our estimates were within the expected range. This substantial amount could contribute to a shift in runoff patterns, which is especially worrisome given the frequency of rain events producing high flows in the region.

Our observations of transpiration accounted for a greater proportion of total ET than previously noted in cloud forests where transpiration was only 16% (Ataroff and Rada 2000). Results like these have been found to have impacts on streamflow dynamics. In Mexico, for example, deforestation of cloud forest was associated with more erratic flows during the dry season (García Coll 2002). Bruijnzeel and Scatena (2011) also concluded that conversion of lower montane cloud forests will likely considerably increase runoff locally due to low cloud water interception. Ratios of T:ET approaching 1 may be explained by some dry sunny days where little to no evaporation was taking place. The lower evaporation and shorter LWD we observed in the crop fields seem to corroborate these findings.

We further examined wetness differences between crop types by comparing relative humidity data from sensors in the crop boundary layer. We found that increased turbulent mixing of the taller papaya canopy may counteract longer LWD to some extent. Sweet potato and taro have lower roughness coefficients than the taller and structurally more complicated papaya, creating a more defined boundary layer than in papaya, which acts a pocket of humid air at the canopy. This phenomenon explains the reduced RH in the papaya crop microclimate and may even partially offset the longer

LWD we observed in papaya. Nonetheless, this dampening boundary layer effect combined with greater surface area of papaya leaves resulted in the net effect of longer LWD in papaya than shorter crops.

Asdak et al. (1998) found that rainfall interception loss decreased with reduced canopy cover in progressively more open forest areas, which approximates our result from open canopy forest conditions. Thus, fragmented forest is likely to have an effect on evaporation through decreased interception. This highlights the importance of intact forest canopies on the integrity of this process. While papaya is not as wet as forest, it is still significantly different from field crops like taro and sweet potato. We found statistically indistinguishable trends in LWD between papaya and open canopy forest, suggesting specific crop type can drive LWD. This has interesting policy implications, because it suggests that agroforestry, even of thin short-lived trees like papaya, may provide more hydrological services than field crops. This is an important issue to highlight, as there are many programs focusing on agroforestry in the tropics (Mercer 2004).

Recommendations

Given the growing number of policies citing hydrological benefits of forest conservation in the tropics, there is a need for more tropical case studies of hydrological effects accompanying forest cover changes. Our contribution examines interception and evaporation reactions to deforestation in premontane tropical systems with more than 4000 cm of annual precipitation. Although this insight about LWD was not directly compared to exact measurements of canopy interception or evaporation, the great relevance of our findings for extremely moist environments justifies further study. Particularly in watersheds in the tropics with extensive agriculture, forests will become more significant in water budgeting.

Policy applications for integrating these findings abound in the tropics, particularly in Mesoamerica. Although this has changed over time, Blackman and Woodward (2010) showed that as of 2005 less than a third of the targeted parcels for payment for water services in Costa Rica exhibited hydrological benefits. To enhance efficiency of the Costa Rican national PES program, deforestation-related changes in LWD, evaporation and interception could be measured in different watersheds to comparatively analyze where streamflow dynamics may be particularly sensitive to forest clearing.

Moreover, Mexico's Payment for Hydrological Environmental Services program also targets forests important for water. They stipulate "80% cover" in the selected land parcel; this was interpreted in one situation as 80% of the plot being forested, rather than the 80% density of forest cover per hectare as was intended (Muñoz-Piña et al. 2008). If we applied our ET_{crop} model to these two scenarios the vastly different expected results would serve to reinforce the importance of policy parameters that reflect hydrology.

We have aimed to contribute information about the evaporation of wet leaves, specifically important in the humid tropics. The additive hydrological effects at the watershed scale deduced from our results suggest broader landscape changes accompanying deforestation, although inherent complications exist from scaling between leaf-level and watershed-level effects (Jarvis 1995). Furthermore, these results are more informative with intense removal of forest cover, since severe reductions in leaf area have more potential to alter interception. LWD may not be as important in temperate climates, but in the humid tropics there is potential for this parameter to indicate an effect of deforestation on streamflow, as they have demonstrated a relatively high interception of precipitation compared to arid systems where soil evaporation accounts for more evaporation than intercepted precipitation. Additional research of this topic is needed to fully understand this link.

CHAPTER III

MIXED EVIDENCE FOR THE EFFECTIVENESS OF PUBLIC POLICIES FOR IMPROVING FOREST MANAGEMENT: A SYSTEMATIC REVIEW OF RESEARCH FROM MESOAMERICA

Introduction

Reducing deforestation and forest degradation in the tropics REDD+ (see Agrawal, Nepstad, and Chhatre 2011) is an emerging priority in the global change agenda, yet recent research on forest management in developing countries may be poorly situated to inform current debates. In order for REDD+ to induce changes in forest management, countries must change policies, or introduce new policies, in ways that lead to desired effects on forests. Yet it is not clear whether existing research provides clear answers about which particular policy options lead to improvements in forest management under which circumstances. A large literature on policy options for REDD+ largely focuses on either theoretical models of REDD+ policies (Angelsen and Rudel 2013, Lubowski and Rose 2013) or on evaluating REDD+ readiness activities (Sunderlin et al. 2014), with limited attention to what the past history of forest policy can tell us about the potential efficacy of different policy options. Without a focus on policy evaluation, it is impossible to determine whether a policy aimed at addressing a driver will be effective.

In order to address this gap, we conduct a systematic literature review of research on the associations of public policies with forest cover outcomes in Mesoamerica, with the goal of evaluating the evidence base for the efficacy of policy options in the region.

Our findings highlight significant gaps in our understanding of the impacts of forest policies. Although there is a vast literature on forest management in Mesoamerica, most of the 2387 articles we located did not meet the basic criteria of reporting both about a single policy type and a measurement of forest cover. While some of these studies provided important information about land cover change, or the impacts of policies on social and economic conditions, they also demonstrate that while Mesoamerica is well studied, there is not an overwhelming body of evidence allowing for the evaluation of different policies in different contexts.

We located 157 studies that met our basic criteria. We conclude that some policy types have been extensively evaluated in this region. Protected areas, community-based management, and market-based conservation have all been widely studied in Mesoamerica, and all of them frequently are associated with positive outcomes for forest conditions in this region. The highest proportion of positive results were correlated with market-based conservation: we found no studies reporting negative outcomes with payments for forests – however these results are based on payments schemes in only 2 countries, and it is not clear if the benefits of payments will persist in longer time frames, given the recent termination of Mexico's payments program (Enciso 2015). The forest cover changes related to other kinds of policies, such as agricultural subsidies or forestry regulations have rarely been examined in this region. The scarcity of studies of agricultural subsidies is particularly surprising given that agricultural expansion is widely understood to be a major driver of deforestation globally (Geist and Lambin

2001, Hosonuma et al. 2012, Rudel et al. 2005, Angelsen and Kaimowitz 2001, Carter et al. 2015).

Our findings indicate that the evidence base for designing policies under REDD+ is weaker than commonly understood. In some cases, REDD+ has influenced the policies we studied. This global level mandate has shaped tropical forest management, for example through Costa Rica's innovative PES program. In contrast, it appears there is a noticeable gap in study and implementation of new policies aimed at protecting forest-based hydrological services. While some policy options are well studied, other potential policy options have not been examined or have been examined only in a limited array of situations. On the other hand, there is evidence that some policies have been correlated with improved forest management in most of the contexts in which they have been applied in Mesoamerica. In the remainder of this paper, we provide a conceptual overview of existing literature related to forest policies in the tropics, explain how we conducted our study, and report our results.

Approaches to Studying Tropical Deforestation

There are several research traditions that have focused on studying processes of deforestation and forest degradation, yet each is limited in its approach to the study of policy. Perhaps the most prominent of these research traditions is land change science, which has focused on using remotely sensed data and Geographic Information Systems technology to quantitatively track changes in land use and identify drivers of change. Key drivers of deforestation at local to regional scales, in particular agricultural conversion, have emerged through synthetic work comparing case studies (Geist and

Lambin 2001, Rudel et al. 2005). Based on the many papers attributing deforestation largely to agriculture, we hypothesize that cases that examine subsidies for agricultural activities will report adverse effects on forest cover.

Within this tradition, forest transition theory attempts to explain patterns in forest cover declines, stabilizations, and recoveries commonly resulting from economic, geographic, and sociopolitical factors (Mather and Needle 1998); however, this theory has had difficulty predicting forest transitions due to complexity and lack of data (Rudel 2008b). While understanding drivers of change is important for designing policy interventions, it does not tell us which policies will be effective at shifting those drivers, and focused research on policy impacts has been rare in this tradition (Rudel 2008a). Without a focus on policy evaluation, it is impossible to determine whether a policy aimed at addressing a driver will be effective.

By contrast, research in the common pool resource tradition has tended to focus on local scale governance as a cause of deforestation and forest conservation (Gibson, McKean, and Ostrom 2000, Tucker 2010) using a mixture of case studies, field experiments, and remote sensing of land cover change (Moran and Ostrom 2005, Poteete, Janssen, and Ostrom 2010). The primary finding is that under certain conditions local people can work together to manage their forests sustainably. This tradition is more policy-focused; however, the primary finding does not easily translate into policy advice that can be applied at the national and regional levels at which REDD+ has focused.

The record of community-based natural resource management and decentralization programs has proved quite mixed (Coleman and Fleischman 2012, Dressler et al. 2010, Ribot, Agrawal, and Larson 2006, Ribot and Larson 2005, Tacconi 2007). Community-based management encompasses collective land tenure for management of forests. A prominent example of this is Mexico's *ejidos*, which are cultivated land, pastureland, other land communally owned and managed on a cooperative or individual basis. We hypothesize that since since community-based management policy types are abundant in this region and in cases specifically aimed at forest ownership, by design they should succeed in being correlated with positive forest cover outcomes.

Political ecologists have drawn on similar research tools to the common-pool resource tradition, but tend to develop broader views that emphasize the role of political power and conflict in shaping forest outcomes (Brannstrom and Vadjunec 2014, Robbins 2012). While this approach can help to explain the reasons for land cover change, the tendency to focus on large-scale political forces, leaves aside the question of which policy interventions are likely to succeed.

Contrasting with these three fairly coherent research traditions, a large body of literature evaluates the effects of particular conservation policies. While some of these studies draw on the frameworks described above, many do not. Recent reviews have examined the efficacy of policies such as community-based conservation (Dressler et al. 2010, Andrade and Rhodes 2012, Kothari, Camill, and Brown 2013), market-based conservation (Alston, Andersson, and Smith 2013, Grima et al. 2016, Schomers and Matzdorf 2013, Wunder 2013), and protected areas (Hayes and Ostrom 2005, West, Igoe, and Brockington 2006, Hayes 2006, Nagendra 2008, Porter-Bolland et al. 2012, Bruner et al. 2001). While the success of the latter policy type is not absolute globally, we hypothesize that cases of protected areas in Mesoamerica will generally exhibit a tendency to promote forest cover.

Much of the review literature tends to look at these policies in isolation, without examining interactions with other policy types. In many field settings, multiple policies may be in operation simultaneously: for example, when a community that owns forest land in the buffer zone of a protected area receives payments for protecting its forests (see Champo Jimenez, Valderrama Landeros, and Espana Boquera 2012). New insights can be gained from drawing comparisons between multiple types of policies in multiple political settings.

In order to examine the extent to which these diverse research traditions, put together, can help policy-makers evaluate the appropriateness of different policy options for different conditions, we focus our systematic review on Mesoamerica. Systematic reviews have emerged as important tools in the study of social-ecological systems for synthesizing knowledge drawn from diverse case studies (Cox 2014, 2015, Geist and Lambin 2001, Ostrom, Gardner, and Walker 1994, Poteete, Janssen, and Ostrom 2010, Rudel et al. 2005, Rudel 2008b, Young et al. 2006). Evidence from land change science indicates that the drivers of deforestation vary systematically at the regional level (Rudel et al. 2005). While Mesoamerica represents a relatively small proportion of global forest area, the region is the site of innovative policy experiments. Central America and Mexico are well studied, thus providing potential for policy comparison and observation if particular policy options are likely to be effective (George and Bennett 2005, Kaimowitz 2008).

Methods

We conducted a systematic review and meta-analysis of case studies following methods used in several previous studies (Cox 2014, 2015, Geist and Lambin 2001, Ostrom, Gardner, and Walker 1994, Poteete, Janssen, and Ostrom 2010, Rudel et al. 2005, Rudel 2008b, Young et al. 2006). In our cases, disparities in the unit of measurement of the dependent variable caused difficulty in reporting, making it difficult to prove a policy was responsible for a given effect on forest cover. As such, our results report correlations between policy enactment and measureable forest cover outcomes as opposed to attributing changes in forested area to a given policy.

We searched several of the largest scholarly databases using one search string (listed in Appendix A), which included search terms for all of the countries in Mesoamerica, including Mexico and Central America. We intentionally included databases that search grey literature to ensure inclusion of cases found in conference proceedings, scientific reports, and dissertations. The first author reviewed the abstracts of all 2387 then selected those papers that mentioned in their abstract public policy effects on forest cover were measured in a specific location in Mesoamerica.

The unit of analysis for this study is a documented relationship between a single policy and forest cover change in a single country in Mesoamerica in a single study. One publication may contain multiple units of analysis. For example, Morse et al. (2009) examined both the 1996 Costa Rican forestry law as well as environmental service payments as well as comparing baseline deforestation rate. As the study included two public policies, we coded it as two cases. Likewise, there may be multiple units of analysis which are about the same policy, such as Carr (2008) and Suter (2012) both measuring forest cover in Sierra del Lancandón National Park in Guatemala. Finally, some studies included data from similar policies pursued in multiple countries: for example, Hayes (2007) who measured common-property forests in both Honduras and Nicaragua. Jones (1990) similarly had data from five countries about a land settlement/colonization policy, and was thus coded as five different cases.

The dependent variable for analysis is the associated outcome of the policy on forest cover. Based on the review of abstracts of qualifying cases, we determined whether the case had a positive, negative, or neutral forest cover change. We recorded a positive change if there was a reported decrease in deforestation rate, more forested land area—for example either by afforestation or reforestation—or fewer additional deforested units after the policy was enacted. A negative change was recorded if the policy was linked to increased deforestation rate, more deforested area, or increased fragmentation. A neutral effect was coded anywhere the deforestation rate did not change, the forested area stayed the same, or both a positive and negative change resulted in no net change. Deforested area compared to changes in rate of change would potentially be more straightforward to synthesize across cases, as baseline deforestation rates differ. Adding further irregularity to our data, some cases measured additionality, or only avoided deforestation, while others did not.

Our primary independent variable of interest is the type of policy. A number of kinds of policy tools may be used to encourage or discourage conservation. Protected areas are any tracts of land designated as protected and acknowledged by the national government. Market-based conservation policies include payments for ecosystem services and other incentive programs as delineated in Woodward et al. (2014). Direct forest regulations affect the forestry sector, such as logging bans or deregulated timber transport, and are often national reforms or laws. Community-based forest management policy refers to programs that promote or establish community-based collective land tenure for management of forests, such as the establishment of *ejidos* in Mexico.

Agricultural sector policies consisted of mostly agricultural market or technology subsidies. Some policies promote specific types of agriculture, such subsidies for industrialized monoculture, shade coffee, or pastures on deforested lands for livestock. Socioeconomic policies aim to generate income, alleviate poverty, and improve quality of life. Examples are more widespread, ranging from rural assistance programs to policies aiming to increase alternative livelihoods to forest resource extraction. Land tenure policies similarly overlapped some with community-based management; we coded a land tenure policy if a reported change in property right regime or land tenure by a government intervention was mentioned, such as privatization of forests or provision of more secure property rights.

Results

The initial literature search created a database of 2387 abstracts. Of the 2229 studies that did not meet our inclusion criteria, 175 measured forest cover change, either alone or associated with drivers other than public policy, including 33 methods papers strictly looking at land use and cover change using GIS and remote sensing. 129 publications studied conservation policies but did not measure changes in forest cover. We also excluded studies that were based on aggregated data, reviews of large number of cases or studies examining very vague policies—such as neoliberalization or agroindustrialization (e.g. Blankespoor, Dasgupta, and Wheeler 2014, Hayes 2006, Barbier 2000). Other studies did not include a baseline for measured forest cover change, preventing coding a forest cover outcome. Systematic review of these abstracts identified 158 articles in which 212 cases were identified. The final dataset included 23 dissertations, 10 reports, 7 books, 6 conference proceedings and 112 journal articles in 69 journals (see Appendix B).

	Studies/ 1000 km^2	Agricultural Subsidy	Community- based Management	Forest Sector Regulation	Land Tenure	Mkt-based Conservation	Protected Areas	Development	Total/ country	%/ country
Belize	0.1	-	-	-	1	-	-	-	1	0%
Costa Rica	1.7	3	-	6	2	16	19	3	49	23%
El Salvador	1.8	-	-	-	-	-	-	1	1	0%
Guatemala	0.7	3	3	-	8	-	12	-	26	12%
Honduras	0.2	1	3	1	4	-	3	2	14	7%
Mexico	0.1	13	24	6	16	10	20	11	100	47%
Nicaragua	0.4	-	1	-	4	-	7	-	12	6%
Panama	0.3	2	1	-	3	-	3	-	9	4%
Total/ policy type	-	22	32	13	38	26	64	17	212	-
%/ policy type	-	10%	15%	6%	18%	12%	30%	8%	-	-

Table 1. Cases by country, both as a count and percentage, as well as a normalized number of studies per 1000 km^2 of forested area, plus total policies of each type by country.

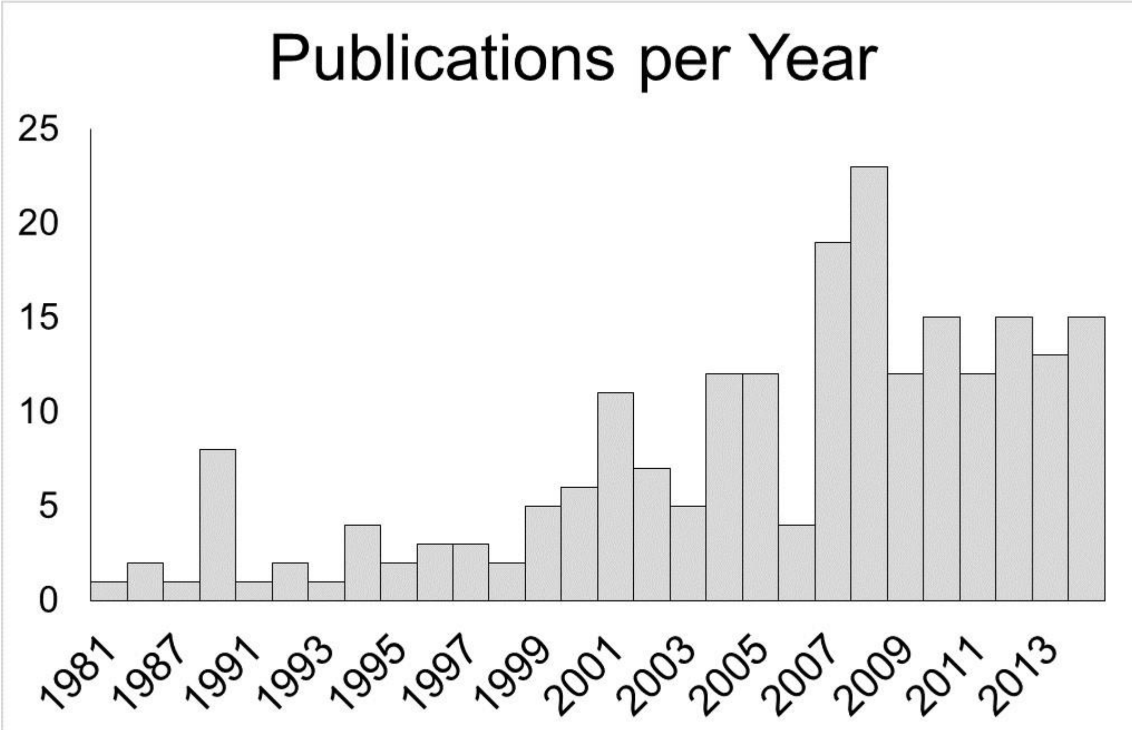

Figure 10. Number of publications by year of publishing, including all cases that fit our inclusion criteria. Each case linked a policy to a forest cover outcome in a country in Mesoamerica: peer-reviewed journal articles as well as grey literature are represented.

70% of cases took place in Mexico and Costa Rica. However, when we normalized number of studies by units of forest area, Mexico had far fewer studies than most other represented countries with only 0.12 studies per 1000 km^2 (Table 1). The two countries with the highest ratio of policy cases per unit forest area were due to vastly different reasons; while Costa Rica is a small country that is well studied per unit area of forest, El Salvador has few studies, but very little forested area left 2,738 km^2 (FAO 2016). There have been an increasing number of publications that fit these criteria since the early 1990s, however it appears that the trend may be leveling off in recent years (see Figure 10).

Beginning as early as the 1980's, a growing number of publications fit our selection criteria, increasing to about 15 publications per year in the most recent decade (see Figure 10). Only 4 journals contributed 4 or more cases to the dataset: *Conservation Biology* (5), *Applied Geography* (4), *Human Ecology* (4) and *World Development* (4). Of the studies present in journals with at least 2 studies, the most profuse ISI categories were Environmental Studies, with 26%, Economics with 11%, and Ecology and Forestry with 10% each (2015).

Policy Effectiveness

Market-Based Conservation

The policy type most likely to report a positive forest cover outcome was market-based conservation, with zero negative cases (see Figure 11). However, there appear to be limitations to what is known about this finding due to only two study locations and methodological constraints.

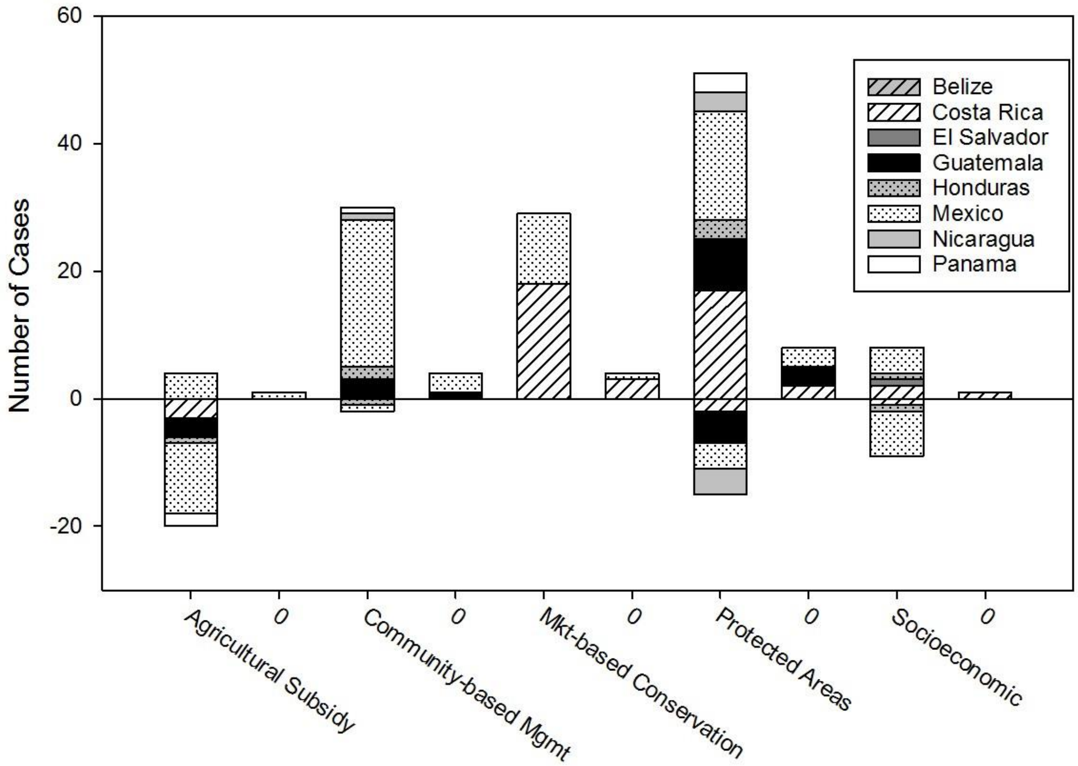

Figure 11. Sum of positive and negative cases for each policy type. 0 corresponds to neutral cases for each policy type. Different patterns correspond to different countries.

Alix-Garcia, Shapiro, and Sims (2012) and Scullion et al. (2011) found modest total avoided deforestation benefits by using a matched controls difference in differences method. Morse (2007) furthermore related incentives for reforestation to increased forest cover, using a mixed-methods approach including a social environmental systems framework lens, Landsat, and surveys. Often cases have a scale mismatch—some cases such as Green et al. (2013) study regionally as compared to Yanez-Pagans (2014), which examines the national level, further confusing conclusions drawn about this policy type.

As these data were only drawn from cases in Costa Rica and Mexico, this scaling issue impedes the generation of generalizable knowledge applicable across the region.

The so-called “unholy trinity” of problems encountered by REDD include leakage, permanence, and additionality. These common challenges highlight the widely cited need for forest targeting improvement. Leakage refers to shifting deforestation to another piece of land and was detected in Alix-Garcia, Shapiro, and Sims (2012) to reduce program effectiveness. Additionality accounts for forest protection that would not otherwise have occurred without the support of the policy, and is examined by Robalino and Pfaff (2013) Sánchez-Azofeifa et al. (2007) and Robalino et al. (2008), likewise demonstrating low avoided deforestation improving over time.

Community Based Management

The second most effective in terms of frequency of positive outcomes was community-based management, with an 81% rate of positive responses, which was similar to but slightly less than market-based conservation (see Figure 11). This further supports our hypothesis that this policy type tends to be related to positive forest cover changes. However, most of these cases were concentrated in Mexico which may limit the utility of the conclusions as Mexico is well known as an unusual case in this regard (Bray et al. 2003). Additionally, trends relating differential success to land tenure and proximity to protected areas were noted across cases.

Fortmann (2014) studied community forest concessions in Guatemala's Maya Biosphere Reserve using the difference in differences method and reported this policy was effective in reducing deforestation among all types of concessions. Barsimantov

(2009) and Barsimantov and Kendall (2012) use econometrics and report both common property tenure and community forestry are generally related to lower deforestation. DiGiano, Ellis, and Keys (2013) look at privatization of *ejidos* and conclude the more communal the ownership of the land, the lower deforestation.

Bonilla-Moheno et al. (2013) had negative forest results, concluding that at the municipality-level "virtually all deforestation has occurred in areas dominated by *ejidos*". However, very low resolution and highly aggregated data add to the ambiguity of the results. Land that was forested but not under some type of productive activity, such as forestry, was not included in the study.

Protected Areas

The third most frequently successful policy type was protected areas, positive in 66% of cases (see Figure 11). Interestingly, a large proportion of cases studied this policy in combination with others. It was observed that strictness of governance contributed to the effectiveness of protected areas, however in some cases deforestation threatened protected area boundaries. What these cases had in common was there were other phenomena described as limiting or explanatory factors in the deforestation narrative, in many cases migration, strength of governance, or agricultural land use change. The overall positive result was somewhat robust in that it had successful cases in 6 countries, published over the course of 27 years. There is a global worry about protected areas acting as "paper parks" which do not work on the ground (Di Minin and Toivonen 2015), but these results imply that in this region at least, they are related to positive forest cover changes.

Andam et al. (2008) Andam (2008), and Andam, Ferraro, and Hanauer (2013) use quasi-experimental methods to estimate additionality of the protected areas system in Costa Rica, finding about 10% avoided forest loss and < 20% reforestation. Figueroa and Sanchez Cordero (2008) and Figueroa et al. (2011) look at aggregate data for dozens of Mexican protected areas, finding a similar success rate to our study. They used an innovative effectiveness index which including percentage of area transformed, rate and absolute extent of change, and comparison to non-protected area.

Agricultural Subsidies

We found negative associations of agricultural subsidies in 83% of cases across five countries (see Figure 11), so we accepted the hypothesis that agricultural subsidies may report negative forest cover outcomes. The 3 positive cases were relating to incentives to search out alternate livelihoods (Schmook 2008) and mixed-vegetation systems utilizing native species (Chargoy Zamora 2004). The latter find that in a situation with shade coffee, policies that promote agroforestry may also be positive for forests. Less than 10% of the total studies examined agricultural subsidies.

Two main examples of subsidized agriculture with associated negative forest outcomes were livestock production and Mexico's PROCAMPO rural assistance program, which provides payments to farmers based on land area cultivated. Multiple papers studied policies such as bank lending, subsidized credits or provision of titles to incentivize cattle production in Central America at the expense of forest cover (Ibrahim, Porro, and Mauricio 2010, Ledec 1992, Arroyo-Mora et al. 2005). PROCAMPO was likewise linked to deforestation (Klepeis and Vance 2003, Klepeis 2003), although

Chowdhury (2006) reported the policy reduced deforestation at the parcel-level, highlighting a need for cross-scale analyses.

All Other Policy Types

Compared to the four previously discussed policies with clear discernable patterns, which comprised 68% of the studies we found, the remaining 32% of the cases fall under deforestation regulation (6%), socioeconomic development programs (8%), and land tenure policies (18%).

Deforestation regulations had a 54% positive correlation rate however this was a result of only 7 positive cases, restricting analysis of this category. Socioeconomic development programs were as likely to be associated with a positive as negative effect on forest cover. Once again, however, the 47% of positive cases were of limited significance given the small sample size. The effect of land tenure reforms in this dataset was ambiguous and most cases (63%) were published more than ten years ago. We were not able to discern why some cases led to improved forest cover and some did not, in part because of the wide variety of policies captured under this term (Robinson, Holland, and Naughton-Treves 2014).

Discussion

These results demonstrate that some types of policies have a positive track record in Mesoamerica: studies of payments for ecosystem services, government protected areas, and community based management show that all of these policies are often correlated with positive forest cover outcomes. Furthermore, we also demonstrate that one type of policy, agricultural subsidies, is strongly associated with declines in forest cover. As we will discuss below, our findings are limited by the data collected in past studies. While Mesoamerica is a very well-studied region, most studies we located did not measure both our independent and dependent variables, and even those that did rarely attempted to measure issues such as leakage and additionality. Thus, while we suggest some practical implications to our work, perhaps our most important finding is that evidence supporting all kinds of policy interventions related to deforestation is weaker than widely understood.

We found that some policy types, market-based conservation, community-based management, and protected areas were often seen in areas with positive forest cover changes most of the time. Given the controversial literature over the effectiveness of these policies (Coleman and Fleischman 2012, Dressler et al. 2010, Ribot, Agrawal, and Larson 2006, Ribot and Larson, 2005, Tacconi, 2007), these are somewhat surprising findings. There could be a publication bias, both due to the limited regions of study and tendency to leave out reporting of failed cases. Additionally, reported outcomes of forest cover change based on perceived change may lead to study biases. Nonetheless, these programs seem to have contributed to how these cases achieved overwhelmingly positive forest cover outcomes.

The associated successes attributed to these programs may be tied to the specific countries' abilities to implement policies. In this case, Costa Rica and Mexico, which account for the vast majority of cases of market-based conservation and community management (see Figure 11), have stable governments, are considered relatively wealthy, and have seen high success in forest conservation in general.

Grima et al. (2016) classified a payment for ecosystem service scheme as "partially successful" if it met the program goals however had a tradeoff in terms of social, environmental, or economic outcomes. Their tiered approach reduced successful cases in their study by 30%, suggesting if we had done a similar correction we would have a less positive outcome. Many of our cases examined Mexico's national PES program, which will allegedly not create new contracts, meaning that in five years all contracts will have ended (Enciso 2015). This will provide an opportunity to test the frequent concern that this will crowd out land owners' intrinsic motivation to preserve forest (Fisher 2012).

Given the apparent importance of agricultural conversion as a cause of deforestation, few studies simultaneously examined policies from that sector along with others. Among the few, Bray et al. (2004) and Bray and Klepeis (2005) found that the lowest rate of net deforestation was associated with both agrarian reform and community-based management, although the relative contributions of the policies to the low rate were not elucidated.

Our study was unable to draw meaningful conclusions about the likelihood of land tenure reforms to positively impact forest cover. Both cases seeming to promote or condemn private property rights have reported (Robinson, Holland, and Naughton-Treves 2014). Duran et al. (2011) ran a comparison of Mexican communities and found the one with informal privatization of land parcels for alternate land uses underwent more deforestation than other communities with communal land. 18% of cases reported about forest cover change related to this policy type. Yet, less than ten cases focused on forest sector regulations. This suggests that policies regulating forestry are likely not the best way to curb deforestation. Rather, it is the other types of policies that are more frequently studied and more widely implemented that will have a larger aggregate impact on forest cover in this region.

Across all policy types, few studies address the problems of additionality, leakage, and permanence, which are vital to the design of REDD+ mechanisms (Angelsen 2008). If conservation policies preserve forests that would have been preserved anyway due to remoteness, steepness, or poor soils, or if they conserve forests in one area which leads to greater degradation somewhere else, or if they conserve forests but only temporarily, this should alter whether outcomes are considered successes or not (Atmadja and Verchot 2012). Additionality, leakage, and permanence are notoriously difficult to measure, thus more effort is needed to understand whether policies, including the ones we have highlighted here as successes, are as successful as advertised.

In many regions of the world multiple policies operate simultaneously; for example, a forest may be in the buffer zone of a protected area, have community-based management, and receive both agricultural subsidies and payments for ecosystem services. Yet less than 25% of the studies we found examine interactions between policy types. Among these cases, we observed mixed results of the main policy tools we have examined. Some evidence showed community-based management and protected areas together work to protect forest cover whereas one policy alone will not (Ellis and Porter-Bolland 2008, Cardenas Hernandez 2008, Baylis, Honey-Rosés, and Ramírez 2012).

Other cases showed market-based conservation in conjunction with either protected areas or community-based management were successful (Honey-Rosés, Baylis, and Ramirez 2011, Fagan 2014, Morse et al. 2009, Cortina Villar et al. 2012).

There was a large diversity of methods and reporting styles used to measure forest cover change which could prevent easy comparison of cases. Some positive cases cited decreased deforestation rates while others reported more forested hectares as a result of a policy or in conjunction with a policy being enacted. The result of this mismatch is that our outcome variable, in order to stay consistent, has eliminated some data. This is problematic when interpreting trends for use in policy-making, as certain policy types may encourage reforestation while others may provide little avoided deforestation but promote poverty alleviation. If more cases were reported similarly, it might be possible to conduct quantitative metaanalyses with directional effects weighted by magnitude.

There are also issues of spatial scale that arise when studying a specific small region. Using countries as a unit of analysis often relies on aggregate data, which presents potential for ecological fallacy (Freedman 1999). Moreover, focusing on a relatively diverse set of countries in terms of political history means some policy types had low sample sizes.

Some regions were understudied. We originally intended to include the Caribbean but could not identify a significant number of studies there. Research tends to cluster within countries, as is the case in Mexico. A fairly large number of studies focused on protected areas in Campeche and forest concessions in other parts of the

Yucatan Peninsula; some of the successful forestry communities in Oaxaca; and the Monarch Butterfly Reserve in Michoacan. However, other important forest regions of Mexico, such as the Huasteca in several states in east-Central Mexico; the dry forests of much of the central and northern parts of the country; and the extensive tropical forests in and around the Isthmus of Tehuantepec in Oaxaca and Chiapas, are underrepresented in our dataset. Furthermore, some cases studied the same forest repeatedly, effectively biasing country-level results by popularity of study region.

Larger-scale exogenous variables may also impact where people study, such as armed conflicts, policy regime shifts, etc. For example, in south central Mexico most studies of *ejidos* use data from a small subset of communities which are located on major roads and/or are friendly to researchers, and there are few if any studies published from the Lancondon, where sociopolitical conflict may prevent thorough data collection (Meli and Carrasco-Carballido 2008).

Most search results (> 90%) did not enable us to measure policy and reported impact on forest cover. Over 300 studies looked at land use change without examining whether policy may be having an impact or evaluated policies without measuring forest cover change. The alternative causes of deforestation these papers included all the proximate and underlying causes of deforestation outlined in Geist and Lambin (2002). Often policy evaluations measured outcomes other than forest cover change related to conservation policies, ranging from biophysical indicators (such as carbon sequestration or biodiversity conservation) to social outcomes like reduction in poverty. These outcomes are also important, but are not regularly reported in the studies we examined.

Recommendations

Our results point to several recommendations. First, to improve forest conditions, we can recommend three policy types as the most likely to be related to successful forest cover change in Mesoamerica: market-based conservation, community-based management and protected areas, given limited evidence. Second, while most large-scale studies and meta-analyses find that agricultural expansion is the main cause of deforestation around the world (Geist and Lambin 2002, Rudel et al. 2005, Arroyo-Mora et al. 2005, and Hecht and Saatchi 2007), few studies focus on the role of agricultural policies in encouraging deforestation. New initiatives to restructure social support programs currently delivered through agricultural subsidies could be an effective means to slow deforestation by, for example, shifting money out of agricultural subsidies that encourage deforestation and towards social support programs that encourage school attendance, such as Mexico's PROSPERA (IMSS 2015). We found little research from this region tying social programs to forest cover change, yet social programs distribute far more money than conservation programs, and there is broad evidence connecting human welfare to deforestation (Robalino et al. 2014, Ferraro and Hanauer 2011, Alix-Garcia, Janvry, and Sadoulet 2008, Yanez-Pagans 2014, Ferraro and Hanauer 2014).

Understanding the complex interactions between agricultural subsidies, social programs, and traditional environmental policies will require improved research designs that can evaluate the interacting effects of multiple policies across contexts, while accounting for additionality and leakage (Anselin, Florax, and Rey 2013).

CHAPTER IV

CONCLUSIONS

Often policies for watershed and forest management do not rely on complete scientific evidence. We ultimately have provided a resolution to one instance of this larger problem. We report that in Costa Rican premontane forests, deforestation will likely increase runoff flow and variation. Using LWD to simulate above-canopy interception, we are better able to understand the evaporative component of the water budget. This adds to the evidence that the Costa Rican national PES policy, which aims to provide stable water quantity, may indeed promote that goal by protecting premontane forests. We also have shown that there is support for the ability of specific policy types in Mesoamerica to be associated with positive forest cover outcomes.

It is a concern if conservation program goals are being based on ambiguous or sparse evidence, as it is desirable to create effective policies based on current science. As an example, in multiple cases in Southeast Asia, upstream agriculture was perceived to be the cause of reduced water availability for lowland irrigation (Bonell and Bruijnzeel 2005, Poffenberger 1999, Sitthisuntikul 2013), whereas the actual cause was expansion of downstream irrigated orchards and reduced rainfall (Laungaramsri 2000, Schmidt-Vogt 1998). If policy were enacted restricting upstream water use for irrigation, it would prove ineffective if the actual scientific explanation for the water reduction were not known. This example exemplifies how science is essential to understanding processes that are being managed by policy in order to reach successful outcomes.

Recommendations

In regions where canopy interception of rainfall is an important component of the water budget, LWD may be a viable proxy to compare under different land cover scenarios. We have provided a case study from a little studied region noting that shifts in LWD approximate evaporative changes after deforestation, but there are still other gaps. It can be implied that longer LWD is associated with higher evapotranspiration and lower runoff ratios in tropical forests compared to croplands. We must thus strengthen evaluation of the hydrological impacts of land use decisions that alter vegetation structures, particularly in very moist tropical areas with little study.

We found that some public policies consistently are reported as correlated with positive forest cover outcomes: market-based conservation, community-based management and protected areas. We in part attribute these results to the country of study. Furthermore, we observed that little reporting of additionality along with diversity of methods and reporting styles limited our interpretation of the data. It is essential future assessment is more systematic in order to better draw conclusions from evaluation and prescribe future policy.

According to Pagiola (2008), and Robalino et al. (2008), the Costa Rican PES scheme suffers from low additionality, indicating the positive forest cover outcomes reported as associated with this policy type may indeed be dampened. This effect could be mediated by more effectively ranking land by hydrological benefits, targeting watersheds of particular utility for water quantity services. Our results help validate the current justifications cited by this policy (FONAFIFO). Using LWD as a surrogate for crop height and leaf area, we indeed found intact premontane forest associated with higher interception, and thus evaporation, which could lead to reduced baseflow and more variable stormflow.

Future policy directed at hydrological services should consider estimates of increased runoff from agricultural conversion in their decision-making process. They should target watersheds with high flood hazard potentials associated with large-scale deforestation. Future work should explore more case studies to strengthen models of land use change and associated hydrological alterations, ultimately the science behind the policy-making.

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APPENDIX A

SEARCH STRING AND DATABASES

In order to keep this literature search systematic, I developed a series of search terms intended to keep a narrow focus of literature. I specified based on region, research paradigm, main policy types, and forests. My search was as follows, using Boolean search terms.

deforest* AND ("Costa Rica" OR Mexico OR Guatemala OR Honduras OR "El Salvador" OR Nicaragua OR Belize OR Panama OR "Central America" OR "Mesoamerica" OR "the Americas") AND ("pay* for eco* service*" OR "PES" OR "environment* service*" OR "compensation" OR "reward" OR "Pigouvian" OR "protect* area*" OR park* OR forest* OR ban OR law OR REDD* OR "reducing emissions from deforestation and forest degradation" OR "carbon credit" OR "carbon sequest*" OR "carbon trading" OR "carbon market*" OR "environment* polic*" OR "polit* eco*" OR conserv* OR "common pool resource*" OR "LUCC" OR "LCS")

I searched in the following databases: Web of Science, CAB abstrats, GreenFILE, Cusiness Source Complete, EconLit, Environment Abstracts, Environment Complete, Ag Econ, worldcat, AGRIS, and ProQuest dissertations and theses global.

APPENDIX B

FULL SPREADSHEET OF ALL CHAPTER III RESULTS

Forest Cover Change: + = positive forest cover outcome, - = negative outcome. 0 = neutral outcome. Policy type: PA = protected area. DR = deforestation regulations. SE = socioeconomic development program. CBM = community-based management. MBC = market-based conservation. LT = land tenure or property rights policy. AS = Agricultural Subsidies. Countries: B = Belize. CR = Costa Rica. E = El Salvador. G = Guatemala. H = Honduras. M = Mexico. N = Nicaragua. P = Panama.

Authors, Primary	Title Primary	Periodical Full	Pub Year	Forest Cover Change	Policy Type	Location/scale
Clark,Charles	State Leasehold and Mayan Customary Cultivation Rights in Belize	Society & Natural Resources	2000	-	LT	B
Ibrahim,M.;Porro,R.;Mauricio,R. M.	Brazil and Costa Rica: deforestation and livestock expansion in the Brazilian Legal Amazon and Costa Rica: drivers, environmental degradation, and policies for sustainable land management	Book	2010	-	AS	CR
Place,Susan Elizabeth	ECOLOGICAL AND SOCIAL CONSEQUENCES OF EXPORT BEEF PRODUCTION IN GUANACASTE PROVINCE, COSTA RICA	ProQuest Dissertations and Theses	1981	-	AS	CR
ArroyoMora,J. P.;SanchezAzofeifa,G. A.;Rivard,B.;Calvo,J. C.;Janzen,D. H.	Dynamics in landscape structure and composition for the Chorotega region, Costa Rica from 1960 to 2000.	Agriculture, Ecosystems & Environment	2005	-	AS	CR
Fagan,Matthew;DeFries,Ruth;Sesnie,Steven;Arroyo-Mora,J.;Walker,Wayne;Soto,Carlomagno;Chazdon,Robin;Sanchun, Andres	Protecting forests outside parks: land sparing after a deforestation ban in northern Costa Rica	conference proceeding	2013	+	DR	CR
SanchezAzofeifa,G. A.;Pfaff,A.;Robalino,J. A.;Boomhower,J. P.	Costa Rica's payment for environmental services program: intention, implementation, and impact.	Conservation Biology	2007	+	DR	CR
Morse,W. C.;Schedlbauer,J. L.;Sesnie,S. E.;Finegan,B.;Harvey,C. A.;Hollenhorst,S. J.;Kavanagh,K. L.;Stoian,D.;Wulfhorst,J. D.	Consequences of environmental service payments for forest retention and recruitment in a Costa Rican biological corridor.	Ecology and Society	2009	+	DR	CR
Fagan,Matthew Easton	The changing matrix: Reforestation and connectivity in a tropical habitat corridor	ProQuest Dissertations and Theses	2014	+	DR	CR
Fagan,M. E.;DeFries,R. S.;Sesnie,S. E.;Arroyo,J. P.;Walker,W.;Soto,C.;Chazdon,R. L.;Sanchun,A.	Land cover dynamics following a deforestation ban in northern Costa Rica.	Environmental Research Letters	2013	+	DR	CR
Arana,A.;Campos,J.	Dynamics and factors determinants of changes in forest cover in areas adjacent to the Parque	Recursos Naturales y	2007	0	DR	CR

J.;Velasquez,S.;Villalobos,R.;Dias,A.	Nacional Tapanti Macizo de la Muerte, Costa Rica	Ambiente				
Jones,J. R.	Colonization and environment: land settlement projects in Central America	Book	1990	-	LT	CR
Kuchli,C.	Forests of hope: stories of regeneration	Book	1997	+	LT	CR
Benavides,Francisco	Policy alternatives for balancing conservation and agricultural expansion in the tropics	ProQuest Dissertations and Theses	2005	+	MBC	CR
Rodriguez,J.	Environmental services of the forest: the case of Costa Rica	Revista Forestal Centroamericana	2002	+	MBC	CR
Morse,Wayde Cameron	Payments for environmental services in Costa Rica: Conservation and production decisions within the San Juan-La Selva Biological Corridor	ProQuest Dissertations and Theses	2007	+	MBC	CR
Arriagada,Rodrigo Antonio	Private provision of public goods: Applying matching methods to evaluate payments for ecosystem services in Costa Rica	ProQuest Dissertations and Theses	2008	+	MBC	CR
Robalino,J.;Pfaff,A.;SanchezAzofeifa,G. A.;Alpizar,F.;Leon,C.;Rodriguez, C. M.	Deforestation impacts of environmental services payments: Costa Rica's PSA program 2000-2005.	Environment for Development	2008	+	MBC	CR
Robalino,J.;Pfaff,A.	Ecopayments and deforestation in Costa Rica: a nationwide analysis of PSA's initial years.	Land Economics	2013	+	MBC	CR
Sills,Erin;Arriagada,Rodrigo;Ferraro,Paul;Pattanayak,Subhrendu;Carrasco,Luis;Ortiz,Edgar;Cordero,Silvia;Caldwell,Katie;Andam,Kwaw	Impact of Costa Rica's Program of Payments for Environmental Services on Land Use	report	2008	+	MBC	CR
Ibrahim,Camellia Klara	Changing communities, expanding forests: How constellations of actors change land-use and forest-cover in southwest Costa Rica	ProQuest Dissertations and Theses	2004	+	MBC	CR
Robalino,Juan Andres	Essays on environmental economics and economic development	ProQuest Dissertations and Theses	2005	0	MBC	CR
SanchezAzofeifa,G. A.;Pfaff,A.;Robalino,J. A.;Boomhower,J. P.	Costa Rica's payment for environmental services program: intention, implementation, and impact.	Conservation Biology	2007	0	MBC	CR
Morse,W. C.;Schedlbauer,J. L.;Sesnie,S. E.;Finegan,B.;Harvey,C. A.;Hollenhorst,S. J.;Kavanagh,K. L.;Stoian,D.;Wulfhorst,J. D.	Consequences of environmental service payments for forest retention and recruitment in a Costa Rican biological corridor.	Ecology and Society	2009	+	MBC	CR
Fagan,Matthew Easton	The changing matrix: Reforestation and connectivity in a tropical habitat corridor	ProQuest Dissertations and Theses	2014	+	MBC	CR
Ibrahim,M.;Porro,R.;Mauricio,R. M.	Brazil and Costa Rica: deforestation and livestock expansion in the Brazilian Legal Amazon and Costa Rica: drivers, environmental degradation, and policies for sustainable land management	Book	2010	+	MBC	CR
Castro,R.;Cordero,S.	Tropical forest and the emerging CO2 market. (Forestlands new economic accounting: theories and applications)	Investigacion Agraria, Sistemas y Recursos Forestales	2001	+	MBC	CR
ArroyoMora,J. P.;SanchezAzofeifa,G. A.;Rivard,B.;Calvo,J. C.;Janzen,D. H.	Dynamics in landscape structure and composition for the Chorotega region, Costa Rica from 1960 to 2000.	Agriculture, Ecosystems & Environment	2005	+	MBC	CR

Omang,Joanne	In the Tropics, Still Rolling Back the Rain Forest Primeval	Smithsonian	1987	+	PA	CR
Trines,E. P.	Assessing and monitoring carbon offset projects: the Costa Rican case.	Commonwealth Forestry Review	1998	+	PA	CR
SanchezAzofeifa,G. A.;QuesadaMateo,C.;GonzalezQuesada,P.;Dayanandan,S.;Bawa,K. S.	Protected areas and conservation of biodiversity in the tropics.	Conservation Biology	1999	+	PA	CR
SanchezAzofeifa,G. A.;Daily,G. C.;Pfaff,A. S. P.;Busch,C.	Integrity and isolation of Costa Rica's national parks and biological reserves: examining the dynamics of land-cover change.	Biological Conservation	2003	+	PA	CR
Andam,Kwaw S.;Ferraro,Paul J.;Pfaff,Alexander; Sánchez-Azofeifa,G. Arturo;Robalino,Juan A.	Measuring the effectiveness of protected area networks in reducing deforestation	Proceedings of the National Academy of Sciences of the United States of America	2008	+	PA	CR
Ferraro,P. J.;Hanauer,M. M.;Miteva,D. A.;CanavireBacarreza,G. J.;Pattanayak,S. K.;Sims,K. R. E.	More strictly protected areas are not necessarily more protective: evidence from Bolivia, Costa Rica, Indonesia, and Thailand.	Environmental Research Letters	2013	+	PA	CR
Andam,Kwaw Senyi	Essays on the evaluation of land use policy: The effects of regulatory protection on land use and social welfare	ProQuest Dissertations and Theses	2008	+	PA	CR
Vaughan,Christopher	Patterns in Natural Resource Destruction and Conservation in Central America: a Case for Optimism?	conference proceeding	1990	+	PA	CR
SanchezAzofeifa,G. A.;Rivard,B.;Calvo,J.;Moorthy,I.	Dynamics of tropical deforestation around national parks: remote sensing of forest change on the Osa Peninsula of Costa Rica.	Mountain Research and Development	2002	-	PA	CR
Schelhas,J.;SanchezAzofeifa,G. A.	Post-frontier forest change adjacent to Braulio Carrillo National Park, Costa Rica.	Human Ecology	2006	+	PA	CR
Pfaff,Alexander;Robalino,Juan;Sánchez-Azofeifa,G.;Andam,Kwaw S.;Ferraro,Paul J.	Park Location Affects Forest Protection: Land Characteristics Cause Differences in Park Impacts across Costa Rica	B.E.Journal of Economic Analysis & Policy	2009	-	PA	CR
Broadbent,E. N.;Zambrano,A. M. A.;Dirzo,R.;Durham,W. H.;Driscoll,L.;Gallagher,P.;Salters,R.;Schultz,J.;Colmenares,A.;Randolph,S. G.	The effect of land use change and ecotourism on biodiversity: a case study of Manuel Antonio, Costa Rica, from 1985 to 2008.	Landscape Ecology	2012	+	PA	CR
Andam,K. S.;Ferraro,P. J.;Hanauer,M. M.	The effects of protected area systems on ecosystem restoration: a quasi-experimental design to estimate the impact of Costa Rica's protected area system on forest regrowth.	Conservation Letters	2013	+	PA	CR
Arturo S?ínchez-Azofeifa,G.;Daily,Gretchen C.;Pfaff,Alexander S. P.;Busch,Christopher	Integrity and isolation of Costa Rica's national parks and biological reserves: examining the dynamics of land-cover change	Biological Conservation	2003	+	PA	CR
Fagan,Matthew Easton	The changing matrix: Reforestation and connectivity in a tropical habitat corridor	ProQuest Dissertations and Theses	2014	+	PA	CR
Ibrahim,M.;Porro,R.;Mauricio,R. M.	Brazil and Costa Rica: deforestation and livestock expansion in the Brazilian Legal Amazon and Costa Rica: drivers, environmental degradation, and policies for sustainable land management	Book	2010	+	PA	CR
Arana,A.;Campos,J. J.;Velasquez,S.;Villalobos,R.;Dias,A.	Dynamics and factors determinants of changes in forest cover in areas adjacent to the Parque Nacional Tapanti Macizo de la Muerte, Costa Rica	Recursos Naturales y Ambiente	2007	0	PA	CR

Brockett,Charles D.;Gottfried,Robert R.	State Policies and the Preservation of Forest Cover	Latin American Research Review	2002	0	PA	CR
Ferraro,P. J.;Hanauer,M. M.	Protecting ecosystems and alleviating poverty with parks and reserves: 'win-win' or tradeoffs? (Special Issue: Conservation and human welfare: economic analysis of ecosystem services.)	Environmental and Resource Economics	2011	+	PA	CR
Almeyda,Angelica M.;Broadbent,Eben N.;Wyman,Miriam S.;Durham,William H.	Ecotourism Impacts in the Nicoya Peninsula, Costa Rica	International Journal of Tourism Research	2010	+	SE	CR
Carri?¿re,Jean	The Political Economy of Land Degradation in Costa Rica	International Journal of Political Economy	1991	-	SE	CR
Espinoza.,Edgar	Ecotourism markets as a driving force of land-use and land-cover change: the case of Monteverde, Costa Rica	conference proceeding	2008	0	SE	CR
Hecht,S. B.;Saatchi,S. S.	Globalization and forest resurgence: changes in forest cover in El Salvador.	BioScience	2007	+	SE	E
Cabrera Gaillard,Claudio	Los bosques : el Estado les resta importancia?	Revista Forestal Centroamericana	1993	-	AS	G
Pisano,I. V.	Agriculture and forest in Guatemala: a case study in Peten y Sierra de las Minas	Book	1996	-	AS	G
Barraclough,S. L.;Ghimire,K. B.	Agricultural expansion and tropical deforestation: poverty, international trade and land use	Development and Change	2000	-	AS	G
Milian,Bayron	Poverty, deforestation and land tenure institutions: The case of the communities living in Guatemala's Maya Biosphere Reserve	ProQuest Dissertations and Theses	2008	+	CBM	G
Fortmann,Lea K.	Assessing Factors that Contribute to Reduced Deforestation and Successful Community Forest Management in Guatemala's Maya Biosphere Reserve	ProQuest Dissertations and Theses	2014	+	CBM	G
Carr,D. L.	Ladino and Q'eqchi Maya land use and land clearing in the Sierra de Lacandon National Park, Peten, Guatemala. (Special issue: Native food production knowledge systems and practices: alternative values and outcomes)	Agriculture and Human Values	2004	0	CBM	G
Pease,James R.	Resource Problems and Land Tenure in Guatemala	Geogr Perspect	1986	+	LT	G
Castellon,Michael Joseph	Dynamics of deforestation: Q'eqchi'-Maya colonists in Guatemala's Sierra de las Minas, 1964-1995	ProQuest Dissertations and Theses	1996	-	LT	G
Carr,David L.	Forest Clearing Among Farm Households in the Maya Biosphere Reserve	Professional Geographer	2005	-	LT	G
Carr,David Lawrence	Rural-frontier migration and deforestation in the Sierra de Lacandon National Park, Guatemala	ProQuest Dissertations and Theses	2002	-	LT	G
Prins,K.	Interaction of changes in environment and society: the case of the Mayan Biosphere, Peten Guatemala.	News of Forest History	2001	0	LT	G
Milian,Bayron	Poverty, deforestation and land tenure institutions: The case of the communities living in Guatemala's Maya Biosphere Reserve	ProQuest Dissertations and Theses	2008	+	LT	G
Jones,J. R.	Colonization and environment: land settlement projects in Central America	Book	1990	-	LT	G
Barraclough,S. L.;Ghimire,K. B.	Agricultural expansion and tropical deforestation: poverty, international trade and land use	Development and Change	2000	-	LT	G
Sader,S. A.;Reining,C.;Sever,T.;Soza,C.	Human migration and agricultural expansion: a threat to the Maya tropical forests.	Journal of Forestry	1997	-	PA	G
Quezada,Maura L.;Arroyo-Rodriguez,Victor;Perez-Silva,Evangelina;Aide,T. Mitchell	Land cover changes in the Lachua region, Guatemala: patterns, proximate causes, and underlying driving forces over the last 50 years	Regional Environmental Change	2014	+	PA	G
Blackman,A.	Strict versus mixed use protected areas: Guatemala's Maya Biosphere Reserve.	report	2014	+	PA	G
	Better Forest Protection and Fewer Wildfires in FSC-Certified Areas	Forestry Chronicle	2008	+	PA	G

Sader,S. A.;Hayes,D. J.;Hepinstall,J. A.;Coan,M.;Soza,C.	Forest change monitoring of a remote biosphere reserve.	International Journal of Remote Sensing	2001	-	PA	G
Suter,Laurel	Land succession and intensification in the agricultural frontier: Sierra del Lacandon National Park, Guatemala	ProQuest Dissertations and Theses	2012	-	PA	G
Egan,Brian Francis	Development, poverty and the environment: The political ecology of deforestation and conservation in Peten, Guatemala	ProQuest Dissertations and Theses	1995	-	PA	G
Prins,K.	Interaction of changes in environment and society: the case of the Mayan Biosphere, Peten Guatemala.	News of Forest History	2001	0	PA	G
Carr,David	Farm Households and Land Use in a Core Conservation Zone of the Maya Biosphere Reserve, Guatemala	Human Ecology: An Interdisciplinary Journal	2008	0	PA	G
Fortmann,Lea K.	Assessing Factors that Contribute to Reduced Deforestation and Successful Community Forest Management in Guatemala's Maya Biosphere Reserve	ProQuest Dissertations and Theses	2014	+	PA	G
Carr,D. L.	Ladino and Q'eqchi Maya land use and land clearing in the Sierra de Lacandon National Park, Peten, Guatemala. (Special issue: Native food production knowledge systems and practices: alternative values and outcomes)	Agriculture and Human Values	2004	0	PA	G
Carr,David Lawrence	Rural-frontier migration and deforestation in the Sierra de Lacandon National Park, Guatemala	ProQuest Dissertations and Theses	2002	-	PA	G
Milian,Bayron	Poverty, deforestation and land tenure institutions: The case of the communities living in Guatemala's Maya Biosphere Reserve	ProQuest Dissertations and Theses	2008	+	PA	G
Ardon,C.;Kammerbauer,J.	Land use dynamics and landscape change pattern in a typical watershed in the hillside region of central Honduras	Agriculture, Ecosystems & Environment	1999	-	AS	H
Southworth,J.;Tucker,C.	The influence of accessibility, local institutions, and socioeconomic factors on forest cover change in the mountains of western Honduras	Mountain Research and Development	2001	-	CBM	H
Forster,Nancy R.	Tenure Systems and Resource Conservation in Central America, Mexico, Haiti, and the Dominican Republic	report	1994	+	CBM	H
Hayes,Tanya Marie	Does Tenure Matter? A Comparative Analysis of Agricultural Expansion in the Mosquitia Forest Corridor	Human Ecology: An Interdisciplinary Journal	2007	+	CBM	H
Southworth,J.;Tucker,C.	The influence of accessibility, local institutions, and socioeconomic factors on forest cover change in the mountains of western Honduras	Mountain Research and Development	2001	+	DR	H
Hayes,Tanya Marie	Does Tenure Matter? A Comparative Analysis of Agricultural Expansion in the Mosquitia Forest Corridor	Human Ecology: An Interdisciplinary Journal	2007	+	LT	H
Southworth,J.;Tucker,C.	The influence of accessibility, local institutions, and socioeconomic factors on forest cover change in the mountains of western Honduras	Mountain Research and Development	2001	+	LT	H
Forster,Nancy R.	Tenure Systems and Resource Conservation in Central America, Mexico, Haiti, and the Dominican Republic	World Bank Environ Paper 8: Econ and Inst Anal of Soil Conserv Projects in Central Am and the Carib	1994	+	LT	H
Jones,J. R.	Colonization and environment: land settlement projects in Central America	Book	1990	-	LT	H
Southworth,J.;Nagendra,H.;Carlson,L. A.;Tucker,C.	Assessing the impact of Celaque National Park on forest fragmentation in western Honduras.	Applied Geography	2004	+	PA	H
Nagendra,H.;Tucker,C.;Carlson,L.;Southworth,J.;Mukunda Karmacharya;Birendra Karna	Monitoring parks through remote sensing: studies in Nepal and Honduras.	Environmental management	2004	+	PA	H
Munroe,D. K.;Nagendra,H.;Southworth,J.	Monitoring landscape fragmentation in an inaccessible mountain area: Celaque National Park, Western Honduras	Landscape and Urban Planning	2007	+	PA	H

Breazeale,D.;Sanchez,J.;Dubon,A.	A case study on converting rain-fed low productivity annual crops to a perennial crops-based Agroforestry System on hillsides in Northern Honduras.	Zeitschrift fur Bewasserungswirtschaft	2010	+	SE	H
Painter,Michael;Durham,William H., eds.	The social causes of environmental destruction in Latin America	Book	1995	-	SE	H
Chargoy Zamora,C. I.	Management of ecological succession as a tool for agricultural diversification and the conservation of tropical rain forest	Book	2004	+	AS	M
Baerenklau,Kenneth A.;Ellis,Edward A.;Marcos-Martinez,Raymundo	Economics of Land Use Dynamics in Two Mexican Coffee Agroforests: Implications for the Environment and Inequality	Investigacion Economica	2012	+	AS	M
Schmook,Birgit	The social dimensions of land change in Southern Yucatan: The intersection of policy, migration and agricultural intensification	ProQuest Dissertations and Theses	2008	+	AS	M
Deininger,K. W.;Minten,B.	Poverty, policies, and deforestation: the case of Mexico.	Economic Development and Cultural Change	1999	-	AS	M
Blackman,Allen;Albers,Heidi;Crooks,Lisa;Avalos-Sartorio,Beatriz	Deforestation and Shade Coffee in Oaxaca, Mexico	report	2005	-	AS	M
Busch,Christopher	Deforestation in the Southern Yucatan: Recent Trends, Their Causes, and Policy Implications	ProQuest Dissertations and Theses	2006	-	AS	M
Wyman,M.;Villegas,Z. G.;Ojeda,I. M.	Land-use/land-cover change in Yucatan State, Mexico: an examination of political, socioeconomic, and biophysical drivers in Peto and Tzucacab.	Ethnobotany Research and Applications	2008	-	AS	M
Schmook,B.;Vance,C.	Agricultural policy, market barriers, and deforestation: the case of Mexico's Southern Yucatan.	World Development	2009	-	AS	M
Klepeis,Peter;Vance,Colin	Neoliberal Policy and Deforestation in Southeastern Mexico: An assessment of the PROCAMPO Program	Economic Geography	2003	-	AS	M
Bray,D. B.;Klepeis,P.	Deforestation, forest transitions, and institutions for sustainability in Southeastern Mexico, 1900-2000.	Environment and History	2005	-	AS	M
Barbier,Edward B.;Burgess,Joanne C.	Economic Analysis of Deforestation in Mexico	Environment and Development Economics	1996	-	AS	M
Barbier,E. B.	Links between economic liberalization and rural resource degradation in the developing regions.	Agricultural Economics	2000	-	AS	M
GarciaBarrios,L.;GalvanMiyoshi,Y. M.;ValdiviesoPerez,I. A.;Masera,O. R.;Bocco,G.;Vandermeer,J.	Neotropical forest conservation, agricultural intensification, and rural out-migration: the Mexican experience.	BioScience	2009	-	AS	M
Skutsch,M.;Rios,E. de los;Solis,S.;Riegelhaupt,E.;Hinojosa,D.;Gerfert,S.;Gao Yan;Masera,O.	Jatropha in Mexico: environmental and social impacts of an incipient biofuel program.	Ecology and Society	2011	0	AS	M
AlixGarcia,J.;Janvry,A. de;Sadoulet,E.	A tale of two communities: explaining deforestation in Mexico. (Special issue: Institutional arrangements for rural poverty reduction and resource conservation)	World Development	2005	+	CBM	M
Alix-Garcia,Jennifer	A spatial analysis of common property deforestation	Journal of Environmental Economics and Management	2007	+	CBM	M
Huelsz,J. A. S.;NegrerosCastillo,P.	Community-based forest management in Quintana Roo, Mexico. (Forests under pressure: local responses to global issues.)	report	2014	+	CBM	M
Chowdhury,R. R.	Household land management and biodiversity: secondary succession in a forest-agriculture mosaic in Southern Mexico.	Ecology and Society	2007	+	CBM	M
Chowdhury,R. R.	Differentiation and concordance in smallholder land use strategies in southern Mexico's conservation frontier.	Proceedings of the National Academy of Sciences of the United States of America	2010	+	CBM	M

Ellis,E. A.;PorterBolland,L.	Is community-based forest management more effective than protected areas? A comparison of land use/land cover change in two neighboring study areas of the Central Yucatan Peninsula, Mexico.	Forest Ecology and Management	2008	+	CBM	M
Bray,D. B.;Duran,E.;Hugo Ramos,V.;Mas,J. F.;Velazquez,A.;Balas McNab,R.;Barry,D.;Radachowsky,J.	Tropical deforestation, community forests, and protected areas in the Maya Forest.	Ecology and Society	2008	+	CBM	M
Navarrete,J. L.;Ramirez,M. I.;PerezSalicrup,D. R.	Logging within protected areas: spatial evaluation of the monarch butterfly biosphere reserve, Mexico.	Forest Ecology and Management	2011	+	CBM	M
Barsimantov,James	What makes community forestry work? A comparative case study in Michoacan and Oaxaca, Mexico	ProQuest Dissertations and Theses	2009	+	CBM	M
Bray,D. B.;Ellis,E. A.;Armijo Canto,N.;Beck,C. T.	The institutional drivers of sustainable landscapes: a case study of the 'Mayan Zone' in Quintana Roo, Mexico.	Land Use Policy	2004	+	CBM	M
Bray,D. B.	Toward 'post-REDD+ landscapes': Mexico's community forest enterprises provide a proven pathway to reduce emissions from deforestation and forest degradation.	report	2010	+	CBM	M
Barsimantov,J.;Kendall,J.	Community forestry, common property, and deforestation in eight Mexican states.	Journal of Environment & Development	2012	+	CBM	M
SanchezAzofeifa,G. A.;Quesada,M.;CuevasReyes,P.; Castillo,A.;SanchezMontoya,G.	Land cover and conservation in the area of influence of the Chamela-Cuixmala Biosphere Reserve, Mexico. (Special Issue: Ecology and regeneration of tropical dry forests in the Americas: implications for management.)	Forest Ecology and Management	2009	+	CBM	M
DiGiano,Maria Louise	Privatizing the commons? A political ecology of Mexico's 1992 agrarian reform in Quintana Roo, Yucatan Peninsula	ProQuest Dissertations and Theses	2011	+	CBM	M
DiGiano,M.;Ellis,E.;Keys,E.	Changing landscapes for forest commons: linking land tenure with forest cover change following Mexico's 1992 agrarian counter-reforms.	Human Ecology	2013	+	CBM	M
Bonilla-Moheno,M.;Redo,D. J.;Aide,T. M.;Clark,M. L.;Grau,H. R.	Vegetation change and land tenure in Mexico: a country-wide analysis.	Land Use Policy	2013	-	CBM	M
Chowdhury,R. R.	Landscape change in the Calakmul Biosphere Reserve, Mexico: modeling the driving forces of smallholder deforestation in land parcels. (Special issue: Are parks working? Exploring human-environment tradeoffs in protected area conservation)	Applied Geography	2006	+	CBM	M
Duran,E.;Bray,D. B.;Velazquez,A.;Larrazabal,A.	Multi-scale forest governance, deforestation, and violence in two regions of Guerrero, Mexico.	World Development	2011	+	CBM	M
ChampoJimenez,O.;ValderramaLanderos,L.;EspanaBoquera,M. L.	Forest cover loss in the Monarch Butterfly Biosphere Reserve, Michoacan, Mexico (2006-2010).	Revista Chapingo.Serie Ciencias Forestales y del Ambiente	2012	0	CBM	M
Barbier,Edward B.	Institutional Constraints and Deforestation: an Application to Mexico	Economic inquiry	2002	0	CBM	M
ManzoDelgado,L.;LopezGarcia,J.;AlcantaraAyala,I.	Role of forest conservation in lessening land degradation in a temperate region: the Monarch Butterfly Biosphere Reserve, Mexico.	Journal of Environmental Management; 2014.138:55-66	2014	0	CBM	M
Barry,D.;Bray,D.;Madrid,S.;Merino,L.;Zuniga,I.	Sustainable forest management as a strategy to combat climate change: lessons from Mexican communities.	Sustainable forest management as a strategy to combat climate change: lessons from Mexican communities; 2010.:40 pp	2010	+	CBM	M
Forster,Nancy R.	Tenure Systems and Resource Conservation in Central America, Mexico, Haiti, and the Dominican Republic	World Bank Environ Paper 8: Econ and Inst Anal of Soil Conserv Projects in Central	1994	+	CBM	M

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Bray,D. B.;Klepeis,P.	Deforestation, forest transitions, and institutions for sustainability in Southeastern Mexico, 1900-2000.	Environment and History	2005	+	CBM	M
Baylis,Kathy; Honey-Rosés,Jordi;Ram?¡rez,M. Isabel	Conserving Forests: Mandates, Management or Money?	conference proceeding	2012	+	DR	M
Duran,Elvira;Velazquez,Alejandro;Bray,David	Deforestation, Forest Resources, Civil Conflict, and Community Forest Management Institutions: A Comparison of Two Watersheds in Guerrero, Mexico	conference proceeding	2005	-	DR	M
Diez Mendez,Jordi	Political change and environmental policymaking in Mexico	ProQuest Dissertations and Theses	2004	0	DR	M
Ravenel,R. M.;Granoff,I. M. E.	Illegal logging in the tropics: a synthesis of the issues.	Journal of Sustainable Forestry	2004	-	DR	M
Barsimantov,J.;Navia Antezana,J.	Forest cover change and land tenure change in Mexico's avocado region: is community forestry related to reduced deforestation for high value crops?	Applied Geography	2012	-	DR	M
Barsimantov,James	What makes community forestry work? A comparative case study in Michoacan and Oaxaca, Mexico	ProQuest Dissertations and Theses	2009	-	DR	M
Haar,G.	Peasant control and the greening of the Tojolabal highlands, Mexico. (Tropical forest resource dynamics and conservation: from local to global issues)	report	2000	+	LT	M
Emanuel,R. M.;Greenberg,J. B.	Lluvia Enojada-Tyoo Kuasi': The Political Ecology of Forest Extraction in the Sierra Chatina, Oaxaca, Mexico	Journal of Political Ecology Society	2000	-	LT	M
Durand,L.;Lazos,E.	Colonization and tropical deforestation in the Sierra Santa Marta, Southern Mexico.	Environmental Conservation	2004	-	LT	M
Meli,P.;Carrasco-Carballido,V.	Environmental Restoration in a Tropical Rainforest in Mexico	Ecological Restoration	2008	-	LT	M
Chowdhury,R. R.	Differentiation and concordance in smallholder land use strategies in southern Mexico's conservation frontier.	Proceedings of the National Academy of Sciences of the United States of America	2010	+	LT	M
Barsimantov,James	What makes community forestry work? A comparative case study in Michoacan and Oaxaca, Mexico	ProQuest Dissertations and Theses	2009	-	LT	M
Bray,D. B.;Ellis,E. A.;Armijo Canto,N.;Beck,C. T.	The institutional drivers of sustainable landscapes: a case study of the 'Mayan Zone' in Quintana Roo, Mexico.	Land Use Policy	2004	+	LT	M
Bray,D. B.	Toward 'post-REDD+ landscapes': Mexico's community forest enterprises provide a proven pathway to reduce emissions from deforestation and forest degradation.	CIFOR Infobrief	2010	+	LT	M
DiGiano,Maria Louise	Privatizing the commons? A political ecology of Mexico's 1992 agrarian reform in Quintana Roo, Yucatan Peninsula	ProQuest Dissertations and Theses	2011	-	LT	M
DiGiano,M.;Ellis,E.;Keys,E.	Changing landscapes for forest commons: linking land tenure with forest cover change following Mexico's 1992 agrarian counter-reforms.	Human Ecology	2013	-	LT	M
Wyman,M.;Villegas,Z. G.;Ojeda,I. M.	Land-use/land-cover change in Yucatan State, Mexico: an examination of political, socioeconomic, and biophysical drivers in Peto and Tzucacab.	Ethnobotany Research and Applications; 2007.5:59-66	2008	-	LT	M
Forster,Nancy R.	Tenure Systems and Resource Conservation in Central America, Mexico, Haiti, and the Dominican Republic	World Bank Environ Paper 8: Econ and Inst Anal of Soil Conserv Projects in Central Am and the Carib	1994	+	LT	M
Bonilla-Moheno,M.;Redo,D. J.;Aide,T. M.;Clark,M. L.;Grau,H. R.	Vegetation change and land tenure in Mexico: a country-wide analysis.	Land Use Policy	2013	-	LT	M
Barsimantov,J.;Navia Antezana,J.	Forest cover change and land tenure change in Mexico's avocado region: is community forestry related to reduced deforestation for high value crops?	Applied Geography	2012	-	LT	M

Bray,D. B.;Klepeis,P.	Deforestation, forest transitions, and institutions for sustainability in Southeastern Mexico, 1900-2000.	Environment and History	2005	+	LT	M
Barbier,Edward B.	Institutional Constraints and Deforestation: an Application to Mexico	Economic inquiry	2002	0	LT	M
Honey-Rosés,J.;Baylis,K.;Ramirez,M. I.	A spatially explicit estimate of avoided forest loss.	Conservation Biology	2011	+	MBC	M
CortinaVillar,S.;PlascenciaVargas,H.;Vaca,R.;Schroth,G.;Zepeda,Y.;SotoPinto,L.;NahedToral,J.	Resolving the conflict between ecosystem protection and land use in protected areas of the Sierra Madre de Chiapas, Mexico.	Environmental management	2012	+	MBC	M
Sims,K.;Shapiro,E.;AlixGarcia,J.	Impact of payments for ecosystem services on deforestation in Mexico: preliminary lessons for REDD.	report	2010	+	MBC	M
Scullion,J.;Thomas,C. W.;Vogt,K. A.;Perez Maqueo,O.;Logsdon,M. G.	Evaluating the environmental impact of payments for ecosystem services in Coatepec (Mexico) using remote sensing and on-site interviews. (Special Issue: Payments for ecosystem services in conservation: performance and prospects.)	Environmental Conservation	2011	+	MBC	M
Green,K. M.;DeWan,A.;Arias,AB;Hayden,D.	Driving adoption of payments for ecosystem services through social marketing, Veracruz, Mexico	Conservation Evidence	2013	+	MBC	M
Yanez-Pagans,Patricia	Three essays in development and environmental economics	ProQuest Dissertations and Theses	2014	+	MBC	M
AlixGarcia,J. M.;Shapiro,E. N.;Sims,K. R. E.	Forest conservation and slippage: evidence from Mexico's national payments for ecosystem services program.	Land Economics	2012	+	MBC	M
Baylis,Kathy; Honey-Rosés,Jordi;Ram?¡rez,M. Isabel	Conserving Forests: Mandates, Management or Money?	conference proceeding	2012	+	MBC	M
ManzoDelgado,L.;LopezGarcia,J.;AlcantaraAyala,I.	Role of forest conservation in lessening land degradation in a temperate region: the Monarch Butterfly Biosphere Reserve, Mexico.	Journal of Environmental Management; 2014.138:55-66	2014	0	MBC	M
Bauche,Paola	Interactions of payment for hydrological services and forest transitions: A case study of the Rio Cuale watershed	ProQuest Dissertations and Theses	2007	+	MBC	M
Mendoza,E.;Dirzo,R.	Deforestation in Lacandonia (southeast Mexico): evidence for the declaration of the northernmost tropical hot-spot.	Biodiversity and Conservation	1999	+	PA	M
Mas,J. F.	Assessing protected area effectiveness using surrounding (buffer) areas environmentally similar to the target area.	Environmental monitoring and assessment	2005	+	PA	M
Flamenco-Sandoval,Alejandro;Martinez Ramos,Miguel;Raul Masera,Omar	Assessing implications of land-use and land-cover change dynamics for conservation of a highly diverse tropical rain forest	Biological Conservation	2007	+	PA	M
Figueroa,F.;SanchezCordero,V.	Effectiveness of natural protected areas to prevent land use and land cover change in Mexico.	Biodiversity and Conservation	2008	+	PA	M
Figueroa,F.;SanchezCordero,V.;IlloldiRangel,P.;Linaje,M.	Evaluation of protected area effectiveness for preventing land use and land cover changes in Mexico. Is an index good enough? [Spanish]	Revista Mexicana de Biodiversidad	2011	+	PA	M
Pfaff,Alexander;Santiago-Avila,Francisco;Carnovale,Maria;Joppa,Lucas	Protected Areas' Impacts Upon Land Cover Within Mexico: the need to add politics and dynamics to static land-use economics	conference proceeding	2014	+	PA	M
Cardenas Hernandez,Oscar Gilberto	Causes and consequences of deforestation and land-cover change in rural communities of western Mexico	ProQuest Dissertations and Theses	2008	-	PA	M
Roy Chowdhury,Rinku	Landscape change in the Calakmul Biosphere Reserve, Mexico: Modeling the driving forces of smallholder deforestation in land parcels	Applied Geography	2006	-	PA	M
Rayn,D.;Sutherland,W. J.	Impact of nature reserve establishment on deforestation: a test.	Biodiversity and	2011	0	PA	M

		Conservation				
Ellis,E. A.;PorterBolland,L.	Is community-based forest management more effective than protected areas? A comparison of land use/land cover change in two neighboring study areas of the Central Yucatan Peninsula, Mexico.	Forest Ecology and Management	2008	+	PA	M
Bray,D. B.;Duran,E.;Hugo Ramos,V.;Mas,J. F.;Velazquez,A.;Balas McNab,R.;Barry,D.;Radachowsk y,J.	Tropical deforestation, community forests, and protected areas in the Maya Forest.	Ecology and Society	2008	+	PA	M
Navarrete,J. L.;Ramirez,M. I.;Perez Salicrup,D. R.	Logging within protected areas: spatial evaluation of the monarch butterfly biosphere reserve, Mexico.	Forest Ecology and Management	2011	+	PA	M
SanchezAzofeifa,G. A.;Quesada,M.;CuevasReyes,P.;Castillo,A.;SanchezMontoya,G.	Land cover and conservation in the area of influence of the Chamela-Cuixmala Biosphere Reserve, Mexico. (Special Issue: Ecology and regeneration of tropical dry forests in the Americas: implications for management.)	Forest Ecology and Management	2009	+	PA	M
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W.	Tropical deforestation and land use)					
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APPENDIX C

FOREST WATER FLUXES

To understand water fluxes in the premontane transitional rainforest, we start with the water budget equation:

$$0 = P - R - ET - G - \Delta S$$

where P is precipitation, R is runoff, ET is evapotranspiration, G is groundwater recharge, and ΔS is the change in soil water storage. In areas with forested vegetation, canopy rainfall interception leads to evaporation from the leaf surface as an additional means of evaporation—together with soil evaporation.

Large interbasin groundwater transfer to lowland streams and riparian zones in Costa Rica were observed, implying downstream water availability is highly dependent on upstream contributions, given very high runoff ratios in such regions with very high annual rainfall (Genereux and Pringle 1997, Genereux, Wood, and Pringle 2002, Genereux, Jordan, and Carbonell 2005, Genereux and Jordan 2006). In such circumstances, spatially heterogeneous processes such as canopy interception and leaf water uptake may alter the water balance differently than in arid ecosystems. In a Venezuelan cloud forest, canopy interception was over 50% (Ataroff and Rada 2000). Furthermore, species difference has altered evapotranspiration in Costa Rica (Bigelow 2001, Díaz, Bigelow, and Armesto 2007). These dynamics will depend on land use decisions, which directly alter vegetative structures.

Other spatial variables can affect evaporation rates, such as heterogeneous terrain which effects energy and aerodynamics, shading impacts on net radiation, and differential air exchange and wind velocities between sub- and above-canopy atmospheric spaces, not to mention natural altitudinal drainage.

Under wet canopy conditions, evaporation from the leaf surface can compose a significant, often underestimated component of the water budget (Lawrence et al. 2007). Intermittent rain events lead to spatiotemporal variability in plant exposure to radiation and precipitation, which can translate to effects in physiological processes like photosynthesis and leaf wetness duration. Exposed leaves at the vegetative canopy level have been found to dry more rapidly than those in the understory in mature tropical forests (Aparecido et al. In Review).

Among the key equations to estimate potential evaporation (ET_{crop}) are Penman, Penman–Monteith and Priestley–Taylor. In order to estimate evapotranspiration, many models have modified the Penman-Monteith equation (Walter et al. 2000, McMahon et al. 2013). To estimate reference crop ET0 it is common to utilize the FAO56 reference crop equation, a Penman–Monteith equation for a 0.12 m high hypothetical crop with a surface resistance of 70 s m−1, and this technique can be applied to humid conditions (Irmak et al. 2005). This approach typically uses meteorological variables such as temperature, relative humidity, wind speed, and radiation, as evapotranspiration is driven by evaporative energy and atmospheric demand. Under dry canopy conditions in a humid region, canopy and aerodynamic resistance values affect ET estimates (McVicar et al. 2012, Allen et al. 1989, Holwerda et al. 2012, Munro and Oke 1975) lending evidence to the importance of vegetation type on ET.

Evaporation calculation based on the decoupling coefficient (Pereira 2004, Pereira 1973) is similarly based on Penman-Monteith, along with radiation-based ET models applied in tropical systems (Subburayan, Murugappan, and Mohan 2011).

When comparing methods for estimating potential evapotranspiration, it was found that the Penman-Monteith method produced a smaller standard error than any other Penman-derived equation in all global climatic zones (Jensen et al., 1990). Furthermore, for humid locations these other models overestimated lysimeter measurements. The FAO Irrigation and Drainage Paper No 56 on Crop Evapotranspiration (based on Monteith (1965)) has been the largest advance in the past two decades in determining reference evapotranspiration for agricultural and other land uses. The FAO56 modified Penman-Monteith equation is thus considered “standard” for daily or monthly reference estimations (Valiantzas 2013), although it does require numerous supporting equations to convert standard input variables. Its simplicity however yields consistent results, and variations such as the introduction of a shorter reference crop (0.5m) have been successfully implemented (Walter et al. 2000). The number of crop coefficients in circulation has expanded considerably, as well as the understanding of non-traditional conditions of inundation and salt stress (Allen et al. 1998).

As mentioned previously, supporting algorithms increase the robustness of this equation, as only limited weather data inputs are required to estimate reference evapotranspiration. When considering other modified versions of the Penman-derived equation, often similar data are utilized however insufficient field testing in unique situations suggests most of these models are not recommended (McMahon, 2013).